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A Study of Daytime Running Light Design Factors

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16. Abstract

Prior research has suggested that use of daytime running lights (DRL) on operating vehicles can reduce the frequency and severity of collisions. Possible DRL implementations include high-beam headlamps (with reduced intensity), low-beam headlamps, turn signals, parking lamps and dedicated DRL lamps. Questions have, therefore, arisen regarding the impact on DRL effectiveness of a number of lamp design features and parameters. Research issues involve the effects on vehicle conspicuity under daytime illumination but also potential negative consequences of DRL such as masking of adjacent turn signals and glare under dawn/dusk conditions.

The objective of the effort reported here was to obtain data on perceptual effects of DRL intensity, lamp area, color, number of lamps and lamp/background contrast in the above areas. Three experiments were performed to investigate human perfomance as functions of these design parameters in tasks involving peripheral vehicle detection, turn signal detection and rearview mirror discomfort glare produced by DRL.

Detection distance for a vehicle approaching at a 15 degree peripheral angle was influenced primarily by DRL intensity in the range from 0 to 2000 cd. and was greater for dual separated lamps than for a single center-mounted one. Amber lamps resulted in greater detection distances than did clear ones for lamps having areas of 50 to 100 sq. cm. This trend was reversed for 200 sq. cm. lamps. Decrements in probability of turn signal detection were associated primarily with lamp area. Rearview mirror discomfort glare was mainly a function of DRL intensity. Ratings of the degree of glare and the probability of electing to dim the mirror increased regularly with intensity from 500 to 2000 cd. A recommended DRL intensity distribution was developed based on the data.

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TECHNICAL SUMMARY

Experiments were conducted to determine effects of Daytime Running Light (DRL) design parameters on the perceptual performance of human observers in areas including peripheral detection of an oncoming vehicle under daylight conditions, detection of operating turn signals in the presence of a masking DRL and assessment of discomfort glare produced by DRL under twilight conditions.

Background - Data from accident rate field tests have suggested that the use of DRL on vehicles may have potential for reduction of collision likelihood and severity. Legislation requiring the use of DRL has been passed in European countries, including Sweden and Finland, and will go into effect in Canada in 1989. With regard to the possible introduction of DRL in the United States, a number of research and design issues have arisen. These involve effects of design parameters on vehicle conspicuity under daylight condition including central lamp intensity, beam distribution, lamp area, lamp color, number of lamps, lamp background, etc. It has been suggested that a DRL lamp which will be effective in the U.S. may require greater intensity than that of lamps found to be effective in the Northern European countries, in which DRL was first introduced, because of the higher prevailing levels of ambient illumination in the U.S.

Assuming that increased lamp intensity will produce a greater enhancement of vehicle conspicuity under daylight conditions, a second set of questions has arisen which involves possible counter-productive effects of arbitrarily high DRL intensity levels. Factors which have been suggested as possibly limiting DRL intensity include masking of non-equipped vehicles, production of discomfort glare under dawn/dusk conditions and masking of turn signals if the DRL lamps are located in proximity to these. Requirements for limitations on DRL intensity arising from these considerations have been of particular interest to the Canadian government in putting forth a DRL specification.

The above research issues have arisen, in part, because of interest in the relative effectiveness (in terms of both daytime conspicuity and glare/masking) of specific modes of DRL implementation. These include use of high beam headlamps (usually with intensity reduction), low-beam headlamps, turn signals in a normally-on configuration, parking lamps and dedicated DRL lamps. The objective of the research reported here was to conduct a series of empirical investigations of the effects of DRL design parameters on vehicle detection distance under daytime illumination, turn signal masking, and rearview mirror discomfort glare under twilight conditions. Three experiments were performed to assess effects of selected DRL design parameters on the above areas of driver perceptual behavior.

Vehicle Detection Experiment - The distance at detection of a vehicle approaching at a 15 degree peripheral angle was determined under daytime ambient illumination conditions for selected treatment combinations of the following independent variables:

- DRL intensity at H-V - 0, 250, 500, 1000 or 2000 candela
- DRL lamp area - 50, 100 or 200 sq. cm.
- DRL separation - dual separated versus single center-mounted
- DRL lamp color - clear versus amber
- background contrast - white versus black background

Subjects sat at a 15 degree angle to a roadway and faced a primary task display. They were instructed to attend to the primary task. The test vehicle approached at 25 mph along the roadway. A subject responded upon detecting the vehicle in peripheral vision by pressing a hand-held switch which transmitted a signal to distance measurement equipment in the test vehicle. Detection distance was determined from this system and ambient illumination was measured at the end of each trial using a photometer. The data were subjected to regression analysis and analysis of covariance. The regression analysis showed that detection distance increased significantly with DRL intensity. The mean improvement in detection distance was approximately 80 feet when the grand mean at the 2000 cd. intensity level was compared with that for no DRL (0 cd.). For higher levels of ambient illumination (greater than the observed mean of 41912 lux), DRL intensities below 500 cd. had little effect on detection distance.

An analysis of covariance, with the effect of ambient illumination removed statistically, showed that detection distance improved significantly as a function of DRL intensity and separation, with the dual configuration being detected an average of 27 feet farther than the single center-mounted DRL. Amber DRL lamps were detected at greater distances than were clear ones for lamps having areas from 50 to 100 sq. cm. This trend was reversed for 200 sq. cm. lamps. Background contrast produced significant interactions with DRL color and separation.

Turn Signal Masking Experiment - Lamps representing turn signals were mounted adjacent to dual, separated DRL lamps. Probability of correct turn signal detection was determined under daytime ambient illumination conditions for treatment combinations of the following independent variables:

- DRL intensity at H-V - 500, 1000 or 2000 candela
- DRL lamp area - 50, 100 or 200 sq. cm.
- DRL lamp color - clear versus amber
- viewing distance - 250 versus 500 feet

Subjects viewed the test vehicle from a distance and reported the direction of the turn signal which was activated. Ambient illumination was measured during each trial using a photometer. The data were subjected to regression analysis and analysis of covariance with the effect of ambient illumination removed statistically.

The regression analysis showed that the probability of correct detection decreased significantly with increasing DRL lamp area and viewing distance. DRL intensity was not found to exert a significant main effect. Significant interactions were found involving DRL area, color, intensity and distance. In general, for clear DRL lamps, probability of correct detection showed decrements due to increasing DRL area, intensity and viewing distance while more complex interactive effects were noted for amber lamps.

Rearview Mirror Glare Experiment - For the range of DRL intensities under study, glare under dawn/dusk conditions for the oncoming vehicle case were not anticipated to be a problem. A worst case, however, was expected to result from rearview mirror glare produced by a following vehicle due to the minimal distance and horizontal angle which could prevail. Rearview mirror glare was evaluated under twilight ambient illumination conditions for treatment combinations of the following independent variables:

- DRL intensity at H-V - 500, 1000 or 2000 candela
- DRL lamp area - 50, 100 or 200 sq. cm.
- DRL separation - dual separated versus single center-mounted
- DRL lamp color - clear versus amber

The subject was seated at the driver position in a test vehicle. The DRL lamps were mounted 20 feet behind the rear of the vehicle at the same vertical height as the rearview mirror and the driver's eye. Subjects observed the rearview mirror and responded using a 9 point scale of judged discomfort glare. They also indicated whether or not they would flip the mirror to the reduced intensity position if they were driving the vehicle. Trials were run during the period from one-half hour before to one half-hour after sunset. Ambient illumination was measured during each trial using a photometer. The rating data were subjected to regression analysis which showed no significant effect of ambient illumination. Therefore, analysis of variance was performed on the rating data without adjustment for ambient illumination. The main effects of DRL intensity and area were found to be statistically significant.

Probability of mirror dimming response was found to be significantly influenced by ambient illumination, so analysis of covariance was performed with the effect of ambient illumination removed statistically. The main effect of DRL intensity was found to be statistically significant and to consist of a regular increase in probability of dimming response from .13 at a DRL intensity of 500 cd. to .80 at 2000 cd.

Conclusions and Recommendations - The recommended central DRL intensity based on the vehicle detection data was 2000 cd. Beam pattern was not manipulated explicitly as an independent variable because the effect of seeing a particular lamp at a particular angle off of the lamp axis is simply a reduction in apparent intensity, and intensity was an experimental variable. The utility of luminous output at a given horizontal or vertical angle from H-V clearly depends on the likelihood that the driver of a conflicting vehicle will see the lamp from that position. The report authors had previously done work, which was reported elsewhere, on figures of merit for luminous output at various angles. This took the form of calculations of metrics which depended on roadway geometry constraints and assumptions about vehicle conflicts to produce measures of relative utility for a range of angles in the horizontal plane. The figure of merit function was found to have a maximum at 10 degrees left of H-V, so it was recommended that a DRL lamp should have the maximum intensity of 2000 cd. at this angle and that the target intensity for a given horizontal angle should be the product of the figure of merit for that angle and the maximum intensity of 2000 cd.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

1.0 INTRODUCTION

A number of tests and analyses have suggested that the use of daytime running lights (DRL) can substantially reduce multiple vehicle accident rates. Evidence for this assertion has arisen from two types of experimental approaches. Accident rate field tests have generally involved comparison of accident rates for vehicles with and without DRL. DRL design studies have been performed to assess conspicuity or detectability of DRL lamps as a function of design features such as central intensity, intensity distribution, lamp area, lamp color, etc. The results of DRL tests and analyses have led Finland and Sweden to enact national laws requiring DRL, and the Canadian government has proposed a similar law. The potential benefit of DRL in the U.S. traffic system is currently of interest to the U.S. Department of Transportation National Highway Traffic Safety Administration (NHTSA). This paper presents the results of a series of experiments on DRL detectability, glare and turn signal masking. The objective of these experiments was to provide data on the effects of several DRL design parameters.

A central issue in the development of an effective DRL concept is that of lamp intensity and its angular distribution horizontally and vertically. A number of authors, including Attwood (1981) and Rumar (1981), have argued that the mechanism by which any DRL safety benefit will come about is enhancement of performance in peripheral detection of vehicles by drivers. Luminous intensity is the primary design parameter determining the visual effectiveness of a DRL. For a DRL to perform its function of enhancing vehicle conspicuity, an adequate level of intensity is required in the direction along the line of regard of the driver of another vehicle. It can be argued that a DRL intensity increment will always produce a conspicuity and detection performance increment. The shape of the curve may be such that beyond some point further intensity increments produce diminishing returns, so that the benefit is not worth the energy cost. There are other considerations, however, which suggest that a DRL upper intensity limit should be specified. These involve glare and, perhaps, masking of other relevant stimuli due to veiling luminance produced by DRL if these are set to too high an intensity.

Two research questions have arisen in connection with DRL design and development. One involves the degree to which conspicuity in full daylight varies as a function of DRL output intensity and other design parameters such as lamp area, color, etc. The other general question involves the DRL intensity level at which glare and masking will become problems under lower ambient illumination levels. Hypothetical relationships are shown in Figure 1-1.

It is presumed that conspicuity under daylight conditions increases in a negatively accelerated fashion with intensity. This is shown as the conspicuity curve in Figure 1-1. Under low ambient illumination such as dawn/dusk, it has been shown that high intensity levels of DRL may cause masking of critical stimuli such as vehicles without DRL and vehicle turn signals. At some level of

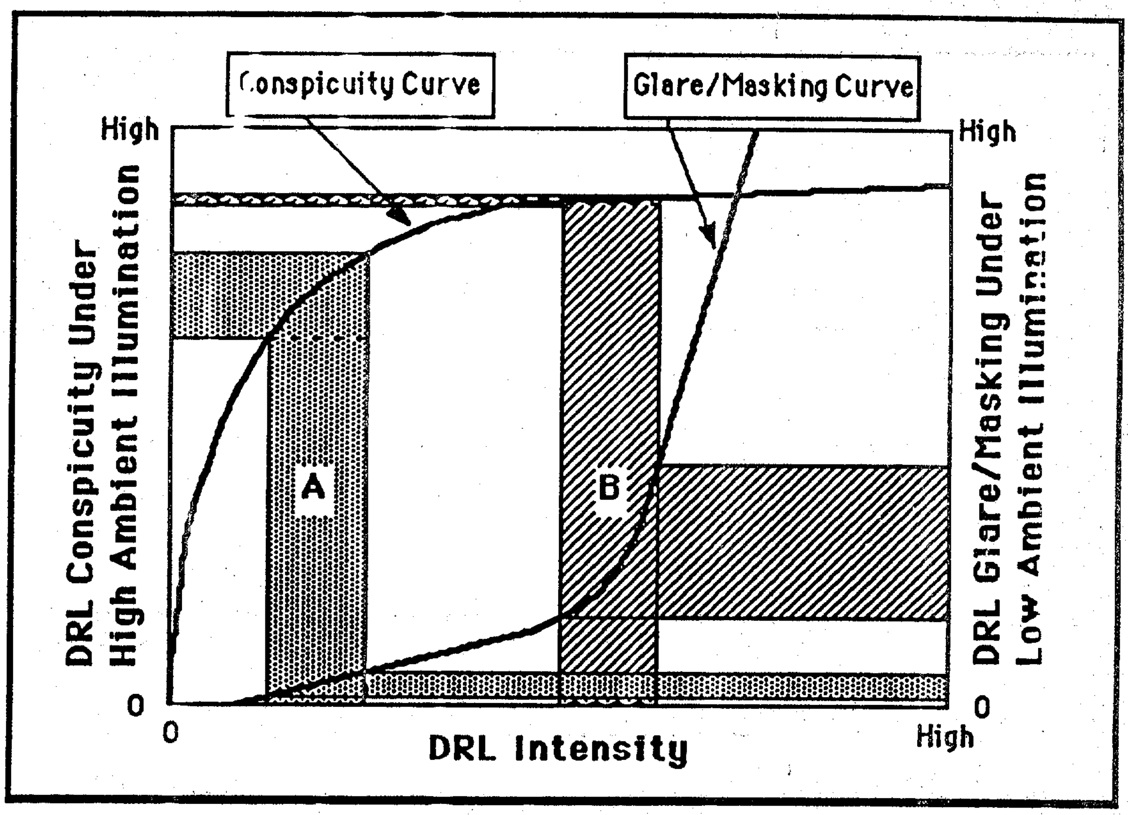

Figure 1-1. Hypothetical Relationship Between DRL Intensity, Conspicuity and Glare/Masking

DRL intensity and some sufficiently low ambient illumination level, DRL lamps will become glare sources, as seen by oncoming drivers. This is represented as a positively accelerated glare/masking curve in Figure 1-1. Figure 1-1 suggests that selection of a suitable DRL intensity level will require a trade-off balancing DRL as a conspicuity treatment under high ambient illumination against DRL as a glare/masking source under low ambient illumination. The intensity increment A results in a considerable increment in conspicuity but little increase in glare/masking. Increment A would probably be judged to be worthwhile. Intensity increment B, however, would probably be a poor choice, because in this region conspicuity is increasing very slowly while a large increase in glare/masking would result from addition of increment B to DRL intensity. While it may not be possible to obtain real data in the handy form shown in Figure 1-1, the logic of a trade-off between DRL conspicuity under high illumination and glare/masking under low illumination is certainly important in the definition of an effective DRL concept.

2.0 ACCIDENT RATE FIELD TESTS

Field tests involve comparison of the daytime accident rate of a group of vehicles equipped with some version of DRL with that of a similar group of vehicles not having DRL. In some cases, all vehicles in a given sample have been equipped with DRL at a certain point in time and the experimental accident rate was determined during a period of time following installation. The control accident rate was then determined from a like period of time prior to installation. This general approach has been termed a before/after test. In interpreting data from such a test, it is always possible that an observed accident rate reduction is due to extraneous non-DRL factors confounded with the pre-DRL and post-DRL time periods. These could include changes in weather, changes in vehicle density, changes in driving practices, etc. The preferred type of test uses a vehicle sample which is split into two matched groups. One of these is equipped with DRL and constitutes the experimental group. The other is not so equipped and constitutes the control group. This approach has been termed a concurrent groups test. Assuming that location, vehicle type and driver factor distributions are matched in the two groups, any observed differences in accident rate between groups can then be attributed to the operation of DRL. The concurrent groups approach is generally preferred on experimental design grounds because it provides control of extraneous variables which might otherwise produce spurious results.

Results of a number of DRL field tests are summarized in Table 2-1. These studies have been reviewed by Attwood (1981), with the exception of the Insurance Institute for Highway Safety (IIHS) test (Stein, 1985). The IIHS study used approximately 2000 DRL equipped automobiles, trucks and vans and compared the accident rate of these with a similar number of control vehicles. The DRL configuration used was vehicle parking lights with special bulbs having a 15 candela (cd.) minor filament. For all vehicles in the test, a seven percent reduction in daytime accident rate resulted from the use of DRL.

The overall pattern of results in Table 2-1 shows a considerable range of effects of DRL. For automobiles and trucks, the accident rate reduction figure of seven percent was found in several studies. Reduction percentages in other studies ranged considerably above this. The degree of reduction due to DRL appears to be roughly associated with DRL intensity. The IIHS study and the Swedish before/after study both reported a seven percent accident reduction. The lighting configurations in the latter were highly variable including auxiliary DRL lamps in the range of 300 - 800 cd. which were required on vehicles manufactured after the law went into effect, headlamps and city lamps which have an intermediate output. The IIHS study used increased intensity parking lamps which generally fell into an intensity range somewhat lower than that of the the Swedish DRL standard. For many of the studies listed in Table 2-1 in which headlights were used as DRL, somewhat greater accident rate reductions can be noted. There is some suggestion of an increasing

Table 2-1. Summary of Daytime Running Light Field Tests

Source	Vehicle Type	DRL Configuration	Test Approach	Approximate DRL Intensity (cd.)	Accident Rate Effect
Greyhound Bus Lines (1960s)	Buses	Headlights	Before/After	6,000 - 15,000	12 - 24 % reduction
AT & T Long Lines (1972)	Automobiles/ Trucks	Headlights	Before/After	6,000 - 15,000	33 - 44 % reduction
Checker and Yellow Cab Companies	Automobiles	Headlights	Concurrent Groups	6,000 - 15,000	7 % reduction
North Carolina Motorcycle Headlight Law (1977)	Motorcycles	Headlights	Before/After	6,000 - 15,000	5 % reduction
Port of NewYork Authority (1965)	Automobiles/ Trucks	Parking Lights	Concurrent Groups	20 - 50	18 - 23 % reduction
Transport Canada (1977)	Automobiles/ Trucks	Headlights	Concurrent Groups	6,000 - 15,000	22 % reduction
Swedish DRL Law (1975-1979)	All Vehicles	Headlights or Auxiliary DRL	Before/After	300 - 15,000	7 % reduction
Insurance Institute for Highway Safety (1982-1984)	Automobiles/ Trucks	Parking Lights	Concurrent Groups	60 - 360	7 % reduction

DRL effect with lamp center intensity.

The exception to this trend is the Port of New York Authority study (Cantilli, 1970). In this study, the DRL configuration was standard parking lights which generally involved rated spherical intensities on the order of 3-6 cd. and center intensities at H-V on the order of 20-50 cd. Despite, the low intensity range, accident rate reductions of 18-23 percent were reported. It should be noted that rear parking lamps were on during daytime in this study and the analysis used rear-end accidents as one of the accident types analyzed. When rear-end accidents were excluded then the lower reduction figure (approximately 18 percent) was obtained.

Perhaps the most interesting characteristic of the Table 2-1 data is that all DRL accident rate field tests conducted to date have shown a positive effect. In all cases, use of DRL has been found to result in apparent accident reduction. In most of the studies summarized in Table 2-1, either statistical analyses were not performed or the results failed to reach statistical significance. Attwood's (1981) argument in this regard is well taken. He noted that if there is, in fact, no benefit of DRL in the general population, then multiple field tests should show about as many negative results as positive ones. The fact that all known studies have produced positive results suggests that the accident reduction in the population due to DRL is not zero, and probably lies in the range from 10-15 percent. The types of collision accidents which appear to be influenced by DRL include head-on and conflicting path (right angle) accidents on main highways. These are often severe in terms of injury and damage. Indeed Cantilli's (1970) analysis suggested that when accidents were graded for severity, using a point scheme based on insurance practice, the reduction in severity due to DRL was considerably greater than that for accident rate alone.

3.0 DRL DESIGN ISSUES AND DESIGN STUDIES

Accident rate field studies, as discussed above, provide the main evidence that DRL can favorably influence accident rates. It has generally been argued that DRL can result in improved detection of vehicles in peripheral vision by drivers (Attwood, 1981; Rumar, 1981). Among other perceptual and cognitive skills, safe driving clearly depends on visual search for, and detection of, approaching vehicles. Accurate object recognition, estimation of vehicle path, estimation of vehicle rate, etc., require visually perceived information which is only available from foveal vision. Neisser (1967) and others have shown that during search, preattentive mechanisms, operating on inputs from peripheral receptors, guide eye fixations on objects in the visual field. Features of objects viewed in the periphery, which enhance conspicuity and likelihood of later fixation on the object, include background contrast, visual angle subtended, shape and motion or change. It is presumed, therefore, that DRL can enhance the contrast of a vehicle appearing at a distance in daylight and increase its conspicuity in peripheral vision thus increasing the likelihood of early detection and the application of foveal vision. The above considerations suggest that the greater the intensity of DRL, the better in terms of detection in daylight. This assertion is probably correct, but there are other considerations which suggest that an upper limit on DRL intensity should also receive research attention and should be selected based on data. Results of some studies of DRL design issues are discussed below.

3.1 <u>DRL Implementation Concepts</u>

Five general DRL configurations have been proposed:

- Headlight high beams
- Headlight low beams
- Turn signals
- Parking lamps
- Dedicated DRL lamps.

3.1.1 Headlights as DRL

Standard vehicle headlamps in either the low or high beam mode have been proposed as DRL. Headlamp low beams provide central intensities up to 20,000 cd. and high beams may provide over 60,000 cd. These lamps are readily detected in daylight - at least when the vehicle is viewed head-on. One argument against standard headlamps as DRL is based on fuel economy. The energy consumed by DRL lamps will be reflected in increased fuel consumption. Teague, Rohter, Gau, Wakely and Viergutz (1980) have examined costs associated with introduction of full-time use of headlights as DRL in the U.S. These authors pointed out that as vehicles are currently wired, simply turning on the headlights during daytime would result in operation of not just the headlights, but also the parking lights. The electrical load of the entire parking lamp system, including parking lamps, side lamps, instrument lamps and associated wiring, is nearly as great as that of low-beam headlights. Some down-sized automobiles were identified which have alternators sized assuming that the headlights are used only at night. Full-time operation of headlights along with wintertime use of heaters and defrosters, or summertime use of air conditioning would result in a long term decline in battery state of charge. The relative abundance of automobiles in this category was small at the time of the Teague et. al. (1980) study but has probably increased in the intervening period, with the current emphasis on fuel economy.

The Teague et. al. analysis points out an important consideration in that it is not desirable from the standpoint of fuel consumption to implement DRL at an arbitrarily high intensity level - particularly if substantial accident rate reduction can be achieved at lower intensity levels. Therefore, the conspicuity enhancement available from DRL at output intensities considerably below that of headlights should be evaluated. Attwood (1981) has argued that an ideal DRL lamp would probably require an intensity no greater than 1000 cd. This recommendation arose from consideration of glare during dawn/dusk, masking of unequipped vehicles during dawn/dusk and cost/benefit analyses of DRL implementation in Canada performed by Ng (1980).

Cost factors favor high beam DRL over low beam when lamp replacement costs are considered. This is because a lamp must be replaced when either filament fails. High beams are rarely used by most drivers, so lamp replacement is usually brought about by low beam filament failure. Use of low beams in daylight would drastically increase the replacement rate, while high beam DRL would simply achieve greater utilization of high beam filaments. However, glare experienced by oncoming drivers is a potent objection to use of full intensity upper beams as DRL. These might be acceptable under high ambient lighting conditions but would probably produce glare under dawn/dusk conditions. Presumably, vehicles would be wired so that high beams would automatically be turned turned on when the engine is running and the headlight switch is turned off. Turning on the headlight switch would give the driver normal low/high beam control. It is often argued, however, that drivers would forget to turn the headlights on (and high beam DRL off) at the approach of sunset and would wind up driving in twilight or dark on high beams.

It has often been suggested that high beams could be operated as DRL, using a dropping resistor or other component to reduce central intensity to something on the order of 5,000 cd. This would solve the glare objection and would extend high beam filament life. It might or might not reduce the energy costs associated with headlights as DRL, depending on details of the implementation.

Lamp beam pattern is another design parameter which would be specified in an effective DRL concept. In addition to the issue of energy consumption, vehicle headlights are not very effective in directing the illumination emitted. This is because headlights are subject to specific Federal design requirements which ensure that they perform their main function - that of illuminating the roadway at night. High beams emit a very narrow cone of illumination centrally, and intensity drops off rapidly outside of this cone. Low beams have a wider beam pattern, but this is aimed down and to the right so as to reduce glare experienced by oncoming divers. An ideal DRL lamp, on the other hand, would have a wide horizontal beam pattern so as to provide conspicuity enhancement over a wide range of angles. Therefore, headlights do not appear to provide an optimum beam pattern for the role of DRL.

3.1.2 Turn Signals as DRL

Turn signals could be used as DRL with a wiring change so that front turn signal filaments would be normally on when the engine is running. Operation of the turn signal control would cause the lamp on the selected side to operate as a turn signal. The characteristic intensity at H-V of turn signals is on the order of 500 to 600 cd. Turn signal reflectors are generally designed to yield a fairly wide beam pattern and this concept would represent an improvement in light distribution over headlamps. There is a question as to whether characteristic turn signal intensity is sufficient to serve the DRL function or whether this would have to be increased. Turn signal assemblies on many current vehicles are made of plastic and would not even stand continuous operation of turn signal filaments at current intensities. Modifications to turn signal housings, and perhaps use of higher intensity filaments, would be required in addition to wiring changes for turn signals to serve as DRL. Consideration of turn signals as DRL has raised the question of whether amber or clear lamps are more effective in enhancing vehicle conspicuity.

3.1.3 Parking Lamps as DRL

Existing vehicle parking lamps appear able to provide an accident reduction effect when used as DRL, based on the Cantilli (1970) and Stein (1985) studies. Many vehicles have combined turn signal and parking light functions, using a dual filament bulb in a single housing, so considerations relevant to turn signals generally apply to parking lamps as well. The main question is intensity in relation to conspicuity and accident reduction benefit. This question was addressed in the IIHS field test reported by Stein (1985) and special bulbs having a major filament rated intensity of 32 cd. and minor filament intensity of 15 cd. were used to increase the output for DRL purposes. Assuming that the current approach of a combined turn signal and parking lamp is retained, the turn signal filament must have a sufficiently high output so that the flash is visible with the parking filament on. This means that use of the minor filament as a DRL would require even higher intensities for the turn signal filament, so the question of heat rejection by the housing is an issue as regards use of parking lights as DRL. For the current turn signal and parking lamp housing to perform DRL functions too, the unit would probably have to be redesigned.

3.1.4 Dedicated DRL Lamps

The most frequent criticism levied against dedicated DRL concepts is cost. Approaches using standard vehicle lamps as DRL have generally been motivated by a desire to reduce cost by using existing lamps. Considerations relative to existing lamp approaches discussed previously, however, have suggested that costs will be incurred for wiring changes, modified lamp housings, resistors, etc. if these other approaches are pursued. The real question is whether the cost of implementing vehicles with DRL is returned in conspicuity and benefits of reduction in accident rates. Since a dedicated DRL unit would be a single purpose conspicuity device, its physical properties could be designed to maximize conspicuity. It has been suggested that an ideal DRL might be similar in design to the fog lamps or "driving" lamps which are offered as OEM items on some automobiles and are available as after-market accessories.

3.2 DRL Conspicuity Under Daylight Conditions

The primary issue in selecting an effective DRL concept involves the luminous intensity level to be specified so that enhancement of conspicuity of equipped vehicles occurs under full daylight. This issue involves both center intensity and angular distribution of intensity due to the design of the lamp reflector. Other factors in DRL design which may also influence daytime conspicuity are color, lamp area, lamp background and number of lamps.

3.2.1 DRL Luminous Intensity

The issue of DRL characteristic center luminous intensity is a fundamental one. Automotive lamps are usually characterized by the intensity in cd. at the center of the lens or at the H-V point, which is basically "straight ahead" as the lamp is mounted in the vehicle. No research effort to date has conclusively demonstrated a specific relationship between DRL intensity and accident rate reduction. A number of experiments and tests have, however, been carried out which indicate how central intensity influences conspicuity and detection.

Horberg and Rumar (1979) reported an investigation of peripheral vehicle detection performance in which lower intensity DRL lamps having outputs from 50 to 400 cd. were compared with a no-DRL control condition and with high beams having 60,000 cd. under ambient lighting conditions of 3,000 to 6,000 lux. Peripheral viewing angles of 30 and 60 degrees were investigated. DRL intensities of 50 and 150 cd. resulted in detection distances which were essentially equal to those for the control condition. Increases in detection distance were noted for DRL lamps having 400 cd. and much greater increases were associated with high beams. A similar set of tests was conducted under twilight conditions from about 100 to 2000 lux. It was found that below ambient illumination levels of about 700 - 800 lux, DRL lamps having intensities from 100 to 300 cd. produced similar detection distance increments. Above this ambient level, detection distances for 100 to 300 cd. DRL lamps did not differ from those for the control condition.

Rumar (1981) has discussed the influence of these studies on the definition of the Swedish Standard SS 3110 (Road Vehicles: Special Running Lights). The minimum intensity allowed at H-V is 300 cd. and the maximum is 800 cd. These values were selected to place the intensity levels in the range where the Horberg and Rumar (1979) data showed a conspicuity benefit, but to avoid twilight or nightime glare problems. The DRL intensity in Sweden is considered effective under lower ambient light levels, but may be less so in broad daylight. Increasing the center intensity to 1000 - 1500 cd. and prohibiting use during dawn/dusk has been considered in Sweden and Finland, but has not been implemented due to concern about glare (Rumar, 1985).

Opinion concerning DRL intensity in the U.S and in Canada has often held that conspicuity increases associated with intensities above the Swedish standard of 300 - 800 cd. may be desirable, although there has been concern about discomfort glare too. The Lighting Committee of the Society of Automotive Engineers has established a DRL Task Force which has conducted a number of investigations of subjective evaluations of DRL effectiveness by observers. Moore (1985a) has reported a test in which observers centrally viewed a stationary DRL equipped vehicle at distances ranging from 0.2 to 1.0 mile and indicated whether or not they could clearly see the car and determine its direction of travel, and whether or not they could clearly see the DRL lamp which was a UF headlamp with the upper beam set to one of several intensities. The dependent measure was the percent of observers who reported being able to see the car and the direction of travel. With no DRL or with the DRL lamp producing 200 cd. at H-V, this percentage declined regularly with distance from 0.2 to 1.0 mile. With DRL intensity set at 5000 cd., response percentage remained at 100 out to one mile. A DRL intensity of 1500 cd. produced a response percentage of 100 percent out to 0.5 mile and declined to about 84 percent at one mile. The results for DRL intensity of 600 cd. showed 100 percent response out to 0.3 mile and then declined regularly to the control level at one mile. The interpretation of these results depends on how necessary detection beyond 0.3 mile is to safe driving. If one were prepared to argue that vehicle detection beyond 0.3 mile (1584 feet) exceeds the distance necessary, then these data would suggest that for central detection of an oncoming vehicle, 600 cd. may be adequate and 1500 cd. almost certainly is.

In a second SAE test of DRL conspicuity (Moore, 1985b) observers viewed a DRL-equipped test car located at peripheral angles ranging from 45 to 83 degrees and distances from 100 to 800 feet. They were instructed to turn to look at the test vehicle and then report the judged effectiveness of the lamps as DRL. DRL intensities of 200, 600 and 1500 cd. were used. At each distance the lamps were rotated so that the observers were "in the beam pattern". The dependent measure was the percent of 24 observers who judged a particular DRL lamp to be an effective signal. For the 1500 cd. condition, 90 to 100 percent of observers judged the lamps to be effective, depending on viewing distance. This was also true of the 600 cd. lamp at distances of 100 and 800 feet. At intermediate distances of 300 and 500 feet, the 600 cd. DRL was judged effective by only 60 to 70 percent of observers. The 200 cd. lamps were judged not effective by a majority of observers at any distance.

This test was replicated using a second set of observers (Moore, 1985c). The 1500 cd. lamps were judged effective by 80 to 90 percent of observers at 100 feet, but this declined to 35 to 45 percent at 800 feet. The 200 and 600 cd. lamps were judged not effective by a majority of observers at all distances. In a third replication under twilight illumination conditions from one half hour before sunset until sunset, a considerable increase was noted in the percent of observers judging lamps to be an effective signal. This was true for all distances and DRL intensities. (Moore, 1985c). This finding is consistent with that of Horberg and Rumar (1979) that the conspicuity of a given DRL intensity level depends strongly on the ambient illumination. The greater the ambient light level, the greater the required DRL intensity for a given degree of conspicuity.

3.2.2 DRL Beam Pattern

The luminous intensity of automotive lamps is generally at a maximum at or near the center, or H-V position, and drops off as the lamp is seen at an angle. This is particularly true of headlamp high beams which concentrate output in a central cone and drop very rapidly outside of this. Other lamps, such as parking lights and turn signals, which are intended to be seen from a wide range of angles often have a much wider beam in the horizontal axis. For a fixed total luminous output, a wide beam can only be obtained by reducing the center intensity via design of the reflector. An effective DRL lamp should enhance conspicuity through a fairly wide forward angle, so a DRL concept will have to address not only central intensity but also intensity over a range of horizontal and vertical angles.

The DRL beam pattern standard developed in Sweden (Swedish Standard SS 3110) is based on the studies of Horberg and Rumar (1979) and Rumar (1980), on discomfort glare considerations and on practical limitations inherent in designing reflectors. Figure 3-1 shows the minimum cd. requirements of the Swedish DRL standard as a function of horizontal and vertical angles.

Kirkpatrick, Heasly and Bathurst (1984) developed an approach for evaluating a beam pattern such as that shown in Figure 3-1. This was based on photometric outputs from an existing fleet of vehicles equipped with DRL. In developing the scheme, it was necessary to establish a single measure of light intensity per vehicle. This figure, termed a figure of merit (FOM), related light intensity at selected horizontal angles to utility in enhancing vehicle conspicuity. In developing the FOM, the authors specified multiple-vehicle daytime accident scenarios, exercised a vehicle conflict model via a series of computer simulations, and finally, using measured photometric data, compiled a recommendation with respect to output beam pattern.

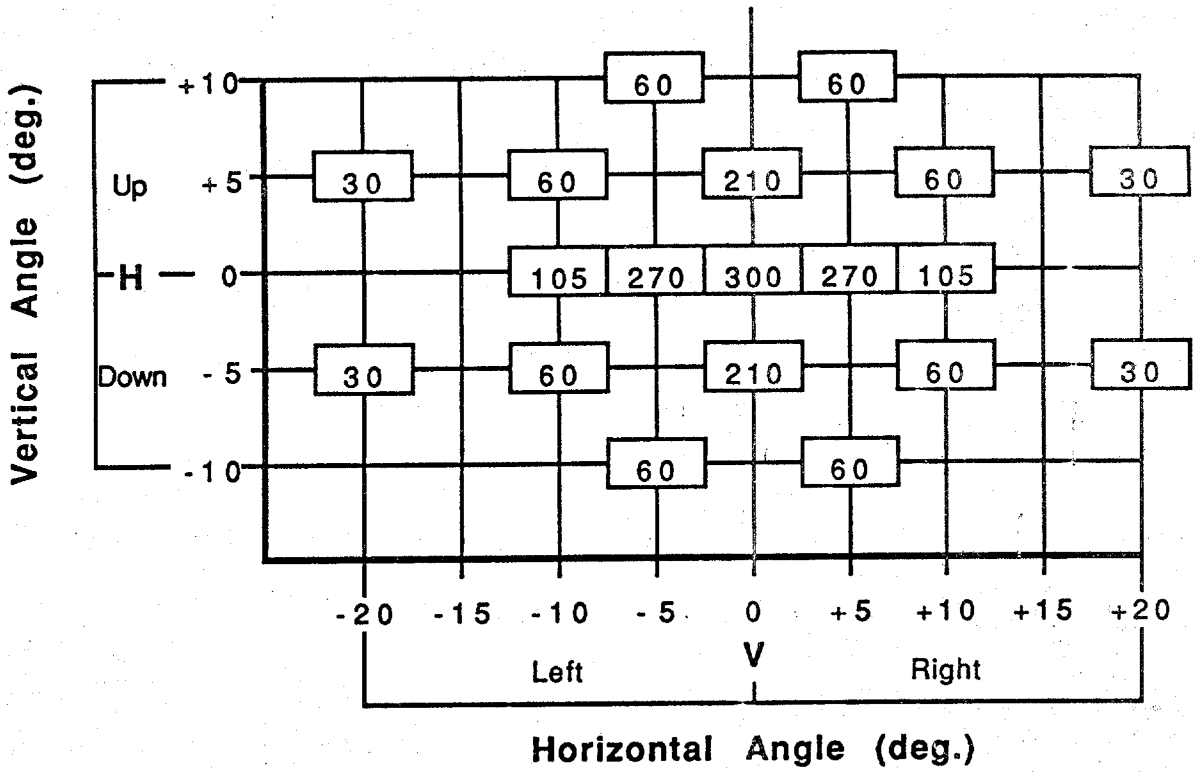

Figure 3-1. Minimum DRL Intensity Values (cd.) From Swedish DRL Standard SS 3110

In one of the SAE DRL tests (Moore, 1985b) the adequacy of a high beam headlight DRL configuration in peripheral vision was investigated. The DRL equipped test car was located at distances of 100 to 500 feet from an intersection. Observers viewed the test car at peripheral angles ranging from 45 to 79 degrees and reported if they could detect the onset of the DRL lamps which ranged in intensity from 1500 to 65,000 cd. The lamps were aimed straight ahead, not at the observers, so that the angle to the observers from the center of the lamp varied from 11 to 45 degrees. At these angles, less than 10 percent of observers reported the onset of the lamp. When the lamps were rotated to point at the observers under the 45 degree peripheral viewing condition, 60 to 82 percent of observers responded, depending on intensity. These data suggest that headlight high beams do not yield the most desirable DRL beam pattern because they are specifically designed to illuminate a narrow field ahead of the vehicle When the headlamps were turned to point at the observers, an appreciable detection rate was obtained, even with large peripheral viewing angles. When, however, the observers were outside of the central beam (11 degrees or greater), few detections were reported.

This test was replicated, using a second sample of observers in an effort reported by Moore (1985c) with two modifications. The DRL lamps were pointed directly at the observers at each distance, and a Type UF headlamp upper beam with an intensity at H-V of 65,000 cd. was compared with a special DRL lamp having a "uniform" beam distribution and intensity at H-V of 1500 cd. Observers reported whether or not they could detect the lamp when it was turned on. The percent of observers reporting detection was zero at peripheral angles of 72 to 79 degrees regardless of lamp type. At a peripheral angle of 45 degrees, 24 percent of observers reported detecting the high beam and 5 percent reported detecting the 1500 cd. lamp. Evidently, even very high intensity lamps are seldom detected at such large peripheral viewing angles. This test was replicated under dusk illumination conditions during the period from one half hour before sunset to sunset. This resulted in increases in the percent of observers who reported detect ng the lamp onset. In the 45 degree peripheral angle condition, 35 percent of observers reported detecting the special DRL lamp and about 56 percent reported detecting the high beam.

Moore (1986a) reported an SAE test of three DRL configurations - headlight low beam, turn signal and fog lamp. Observers faced a straight roadway at right angles and the DRL vehicle approached from either the left or right. DRL lamps were turned on at 500 feet from the observers and were turned off at 250 feet. On a given trial, one configuration was turned on on the right side of the car and another was turned on on the left side. Observers judged which was the more effective. For tests conducted with all lamps adjusted to 600 cd. at H-V, the turn signal was judged the most effective by a majority of observers. Additional testing was conducted comparing the fog lamp and headlight at 1500 cd. The majority of observers judged the fog lamp to be more effective.

This test was replicated using a second group of observers and a stationary test vehicle (Moore, 1986b). The viewing distance was 250 or 500 feet. At both distances, a 600 cd. amber turn signal was judged nearly as effective as a 5000 cd. headlamp high beam. A 600 cd. clear turn signal and the headlamp high beam at intensities of 600 to 1500 cd. were judged to be less effective.

A study of several DRL candidate lamps in comparison with high beam headlights was performed by Macintyre (1985). The lamps used were as follows:

- type 2B rectangular halogen headlamp
- type 1A rectangular halogen headlamp
- amber turn signal with two 32 cd. rated bulbs and 600 cd. at H-V
- four-inch diameter truck turn signal with 50 cd. bulb and 600 cd. at H-V
- four-inch diameter truck turn signal with 50 cd. bulb and 1200 cd. at H-V
- four-inch diameter accessory lamp with 50 cd. bulb and 1600 cd. at H-V
- amber fog lamp with 600 cd. at H-V

Observers sat facing 90 degrees to the path of the test vehicle which approached at 40 mph. A pair of lamps was switched on (one on each side of the vehicle) at a distance of 500 feet from the observers and was switched off at 250 feet. The observers were directed to turn their heads to look at the approaching test vehicle and to indicate which of the lamps was judged more conspicuous. One lamp in a pair was always the type 2B high beam so that all comparisons were made with it. This procedure was similar to that used by Moore (1986a). The results were presented in terms of the intensity of the type 2B headlamp high beam necessary to produce judged conspicuity equal to that of the comparison lamp. The low beam headlamp at full voltage was found to be equivalent to the high beam operating at 3,900 cd. The 1600 cd. accessory lamp was superior to the high beam operating at up to 5,000 cd. The three turn signals tested were equivalent to the high beam at intensities of the latter ranging from 3,100 to 4,000 cd. The fog lamp was equivalent at a high beam intensity of 2,600 cd.

The studies reported by both Moore and Macintyre generally suggest that high beam headlamps are less effective as DRL than are other types of lamps, due to the narrow beam pattern of the former. To be judged as effective as turn signals, foglamps and other types of lamps, high beams had to be operated in the 3000 to 5000 cd. range. This level of center intensity may result in glare problems for drivers who view the beams centrally under low illumination conditions.

3.2.3 DRL Luminous Area and Luminance

In the studies discussed above, DRL lamps have been characterized by luminous intensity in cd. Authors have generally treated DRL lamps seen at distances at which vehicle detection is thought to be desirable as point sources. In general, the effectiveness of an object as a stimulus for visual perception is characterized by its size, its luminance and the luminance of the background against which it is seen. Luminance is a characteristic of an extended source while intensity is a characteristic of a point source and is a measure of lumens of light energy emitted into a solid angle surrounding the point. Intensity has units such as lumens per steradian or candela. An extended light source consists of a lot of points each having an intensity. Therefore, luminance is a measure of lumens per steradian per unit area of the source. The luminance of a visual object (reflected or emitted) in ratio to that of the background defines contrast which, together with object size, is usually taken to describe the detectability of the object. This is true for objects which are extended or have a visually appreciated area. The legibility of printed text, for example, depends chiefly on the size of characters and the character to background contrast. Small objects seen from a long distance, however, may be taken as equivalent to point sources (a star for example). In the DRL literature, lamps have characteristic dimensions of a few inches and are tested at hundreds of feet from observers. At the visual angles subtended, it is usually assumed that these stimuli can be treated as point sources, in which case the main factors in visual effectiveness are intensity (cd.) and distance. In this case, the lamp may be treated as uniform in luminance across its surface and the total luminance is simply the total intensity divided by the area and converted to suitable units.

It is not entirely obvious, however, that this assumption is tenable for DRL studies. When seen from a distance of several hundred feet, the lamps in question do not seem to be dimensionless points. They appear to be extended objects. It is legitimate to ask whether lamp area has an effect on detectability when total intensity is held constant. If so, this fact should impact DRL design. On the other hand, if it is found that area does not influence detectability when total intensity is held constant, then lamp intensity is the correct characteristic to use in describing conspicuity and area can be largely disregarded in DRL design.

Horberg, and Rumar (1979), reported that peripheral detection distance was not affected significantly by luminous area of DRL. Lamp areas of 70 and 200 sq. cm. were compared with controlled intensities of 50 and 150 cd. It was total intensity rather than area which influenced detection performance.

In contrast to the above, Fisher (1974) reported that subjects who compared 178mm (7.12 inches), 102mm (4.08 inches) and 56mm (2.24 inches) diameter lamps "...found the larger sources more conspicuous than the smaller, whereas they found the smaller source brighter and more discomforting than the larger." Subject evaluations were judgments utilizing a semantic differential scale to define "adequate conspicuity" of lamp treatments.

3.2.4 Background Contrast

Dahlstedt and Rumar (1973), have demonstrated that the conspicuity value of a low beam DRL is equivalent, if not superior, to high color contrast between the vehicle and the background. Similarly, Horberg, and Rumar (1979), in determining the effects of DRL on vehicle conspicuity in twilight conditions, demonstrated that effectiveness is partially a function of background illumination levels. In the experiments establishing detection distances for two contrast conditions (snow covered and dry black pavement), they presented subjects with vehicles equipped with varying DRL light intensities (0, 100, 200, 300 cd.). The results varied as a function of the background condition. Under the snow condition, the four DRL intensities did not significantly differ with respect to detection distances above an ambient lighting of 500 lux. Below that level, however, detection distances increased considerably until the limits of the facility were exceeded. Similarly, with the exception of the 300 cd. DRL condition, results of the blacktop experiment yielded insignificant differences in detection distance as a function of DRL intensity above 750 lux. The 300 cd. condition appeared to increase vehicle conspicuity to a larger extent around 1000 lux than did the remaining three light intensity conditions (0, 100, 200 cd.). Additionally, the increase in conspicuity value afforded a vehicle by increased DRL light intensity appeared to increase more dramatically in the snow condit on than in the blacktop experiment.

Blackwell (1970), in investigating contrast, found that the "contrast multiplier" changes significantly as a function of age. The contrast multiplier remains approximately stable through age forty, however as age increases beyond that, so does the contrast multiplier. For example, an individual of age 65 would require almost three times the contrast to detect the same stimulus.

3.2.5 DRL Color

The issue of the optimum color for DRL in enhancing vehicle conspicuity is related to the fact that many vehicles today have amber running lights and turn signals. Attempts to evaluate this factor in relation to the headlamp concept has raised the issue.

While not explicitly evaluating amber and clear sources, Taylor and Sumner (1945) reported that, at constant distances, light colors appeared nearer than did dark colors. Specifically, subjects were requested to equate the apparent distance between a constant reference color source (gray) and a second source (white, yellow, green, red, blue or black). The results indicated that colors with a brightness greater than the background were perceived to be closer than they were in reality. The same general relationship held with colors having a brightness less than the background. Comparing the brightness measurements of the Munsell hue and chroma designations used in the experiment, white had a measured brightness of 75% while yellow had a brightness of 76%. If, as was suggested by the authors, brightness is a major factor in distance estimation, expected performance differences between the two colors would be minimal. The position difference reported between the average yellow and white placement (.34mm) translates to an error difference of about .05%. Results were achieved utilizing a fixed viewing distance of 7.5 feet in a "dark room".

Using paired comparisons of yellow and white lights at intensities of 0, 50, 150, and 400 cd., Horberg, and Rumar (1979) found no significant difference with respect to subjective conspicuity value. The judgements were made on vehicles faced frontally and equipped with DRL of 200 sq. cm. at a distance of 500 meters (1640 feet). Rumar (1980) reported a subjective preference for yellow over white lights with respect to conspicuity value, but found no experimental difference.

Allen, Strickland and Adams (1967), in investigating the relative visibility of white, amber, green and red stimulus lights at varying intensities, reported that target detectability was a function of its relative brightness - not its color.

A number of DRL tests conducted by the Lighting Committee of the Society Of Automotive Engineers have previously been discussed in connection with lamp intensity and intensity distribution. Moore (1985b) found that observer judgments of acceptability of lamps as DRL were influenced by intensity in the range from 200 to 1500 cd. but were not strongly influenced by color (amber versus clear). Similar results were found by Moore (1985c). In contrast, using paired comparisons of DRL devices on the two sides of a test vehicle, Moore (1986a) found that an amber turn signal was judged more conspicuous than either a clear fog lamp or low beam headlamps when all lamps were controlled at 600 cd. In a similar test, Moore (1986b) reported that amber turn signals were judged more conspicuous than a clear turn signal of equal intensity.

3.3 Glare and Masking Due to DRL Under Low Ambient Illumination

Glare is often classified as disability glare which occurs at sufficiently high veiling luminance levels that a decrement occurs in visual performance, or discomfort glare which is intense enough to represent a noxious stimulus but not sufficient to interfere with visual performance (Perel, Olson, Sivak and Medlin, 1984). With sufficient intensity, DRL lamps may cause masking of unequipped oncoming vehicles or may mask turn signals if these and the DRL lamps are mounted close together. These constitute examples of disability glare because critical visual tasks are impeded. DRL lamps of sufficient intensity and proximity may also cause discomfort glare. This is a concern with regard to high beam headlights.

3.3.1 Discomfort Glare

In summarizing the literature with respect to vehicle lighting concerns, Fisher (1974) reviewed research conducted by Jehu (1965) and by the Netherlands Institute for Road Safety Research (SWOV, 1969) in which both sources proposed a town beam with a light intensity between marker lights and dipped headlights. The objective was to develop an improved vehicle marker light which minimized discomfort glare. Specifically, they recommended a lamp having 1/10 the intensity of dipped headlights for use in urban or built-up regions. Additionally, Fisher (1979) reported work conducted by Fisher and Hall (1970) in which they evaluated the proposed town beam in simulated traffic conditions. In assessing preference for the town lamp (as compared to a dipped headlamp), they reported a statistically significant difference. However, this preference "appeared to be based on considerations of comfort rather than visibility." Fisher (1970) stressed that "... headlamp performance is susceptible to production tolerances, aiming and loading of vehicles". Hignett (1970) demonstrated that, due to suspension design, a car carrying its design load can produce unacceptable glare. Therefore, glare and discomfort are not simply a function of lamp design, intensity and beam distribution. Similarly, with respect to quartz halogen lights and lamps that feature "sharp cut-off beams", the "...standard of aiming must be improved if the proportion of glaring lamps is to remain below any particular level." (Harris, 1954).

Fisher and Christie (1963) reported that age differentially impacts the effects of glare. Specifically, older individuals are more seriously impaired by glare than are younger individuals. In attempting to specify the relationship more precisely, they calculated that the veiling luminance for a sixty year old observer is three times that for a twenty year old.

3.3.2 Masking of Unequipped Vehicles

Attwood (1979) studied performance in detecting an oncoming vehicle under dawn/dusk ambient illumination levels. The test vehicle was in the center position of a platoon of three vehicles. Treatments were used in which the first and third vehicles had, or did not have, low beam headlights turned on. The results indicated that the presence of headlamps on the first and third vehicles led to decrements in distance at detection of the unlit center vehicle. This masking effect led Attwood (1981) to recommend a DRL intensity level no greater than 2000 cd. which is considerably less than typical low beam headlights.

3.3.3 Masking of Turn Signals

Fisher (1974) related the results of a study conducted by the Swedish Institute for Road Safety Research in which it was reported that "... as the percentage of dipped headlights increased there was less risk of accident for these drivers and a greater risk for drivers relying on marker lights". The report concluded that present marker lights are inadequate in some circumstances and that there is a need for uniform lighting system so that marker lights are not masked by dipped headlights.

Tests of turn signal masking effects as a function of lamp intensity, viewing distance and location relative to turn signals have been reported by several authors. Moore (1986b) has reported a test of masking of turn signals under daylight conditions by a high beam headlamp with intensity ranging from 0 to 5000 cd. The turn signal was operated at 250 cd. at H-V and its center was separated from the headlamp edge by 3.375 in. Observers faced the test vehicle directly at viewing distances of 500 and 1600 feet and indicated whether or not they could see the operating turn signal. At the 500 foot distance, 95 to 100 percent of observers reported seeing the turn signal. At 5000 cd. this percent dropped to less than 50. At the 1600 foot distance, head lamp intensities as low as 600 cd. resulted in turn signal detection by only 24 percent of subjects. Detections dropped to less than 10 percent for intensities of 1500 cd. and above.

A test of turn signal masking by high beams in daylight was reported by Macintyre (1985). The test vehicle approached the observers at 20 mph and turn signal recognition distance was determined as a function of turn signal to headlight separation and turn signal intensity at H-V in the range from 200 to 1200 cd. The high beam intensity was 3000 to 4000 cd. at H-V. For 6 in. separation, mean detection distance ranged from about 670 to 770 ft. depending on turn signal intensity. For 4 in. separation, the range of mean detection distance was 640 to 710 ft. and for 2.5 in. separation, the range was from 590 to 650 ft.

3.4 DRL Legislation and Standards

In Finland and Sweden national DRL laws were passed in the 1970s. The Swedish DRL standard for minimum intensities is shown in Figure 3-1. The maximum intensity at H-V is 800 cd. The minimum lamp area is about 40 sq. cm. and DRL lamps can be either clear or amber. DRL is required on vehicles manufactured in Sweden after the effective date of the law. Drivers of vehicles manufactured prior to that date can use low beams as DRL. Saab introduced a DRL implementation in 1975 which used reduced intensity low beams and, in 1977, changed to use of cornering, running and parking lights as DRL. Volvo introduced increased intensity parking lights with 300 to 400 cd. at H-V as DRL in 1977 (Rumar, 1981).

In April 1986, the Canadian Department of Transport issued a proposed motor vehicle safety standard requiring DRL as of 1 December, 1989. The proposed standard allows high beam headlamps as DRL if the intensity is limited to a maximum of 7000 cd. at H-V. Low beam headlamps are also allowed with or without reduced intensity. Other lamps may be used and may be clear or amber with a minimum luminous area of 40 sq. cm. and minimum projected area at 45 degrees outboard of 10 sq. cm. The minimum intensities for DRL lamps which are not combined with another regulated lamp are 500 cd. at H-V and 250 cd. at 10 degrees left and right of center in the H plane. A maximum intensity of 1200 cd. is allowed at all points from 20 degrees left to 20 degrees right in the H plane and upward to 10 degrees up.

4.0 EXPERIMENTAL ISSUES

DRL intensity and the resulting level of daytime conspicuity is a primary consideration in definition of a satisfactory DRL design. A minimum intensity level has been provided in field tests through use of parking lamps, or parking lamps with increased intensity filaments. The latter yield characteristic center intensities on the order of 200 cd., and in some cases may approach the minimum value of 300 cd. required in Sweden. The proposed Canadian DRL standard requires a minimum center intensity of 500 cd. which falls in the range of turn signals or dedicated DRL lamps as does the Swedish standard maximum of 800 cd. The Horberg and Rumar (1979) studies showed that effects of DRL intensity on conspicuity in the 100 to 300 cd. range are dependent on ambient illumination. In connection with this finding, Rumar (1981) noted that the prevailing levels of ambient light are considerably lower in Sweden than in the U.S. due to latitude differences. He pointed out that "In December, the sky illumination in Washington is five times that of Stockholm. In June, the dawn and dusk periods in Stockholm are about three times as long as in Washington. The proportion of overcast daylight hours per year is in Washington 43% and in Stockholm 56%. The effect of overcast is larger when the sun is lower." (Rumar, 1981). These considerations suggest that the generally greater illumination levels characteristic of the U.S. compared to Sweden may require greater DRL intensity in the U.S. than is called for by the Swedish DRL standard. Rumar (1985) discussed a proposal to increase the center intensity of the Swedish DRL standard to the 1000 to 1500 cd. range and to prohibit use during dawn and dusk.

These arguments for greater DRL intensity in the U.S. seem well taken. However, it should be kept in mind that Cantilli (1970) obtained significant accident rate reduction using standard parking lights as DRL so that this intensity level may not be entirely ineffective. The low end of the DRL range would appear to be characteristic of improved parking lamps - on the order of 200 to 250 cd. Attwood (1981) has argued, on grounds of vehicle masking in dawn/dusk illumination, that the upper DRL limit should be about 2000 cd. and noted that SAE Standard J579c for low beam headlights limits the intensity at 1.5 degrees left of H-V to 1000 to 2500 cd. due to glare considerations. This suggests something on the order of 2000 cd. as the upper level of DRL center intensity. A number of studies of DRL conspicuity using high beam headlights have employed center intensities up to 5000 cd. This has been done because of the narrow beam pattern of high beams. Intensities of 5000 cd. in the narrow center cone are required if any peripheral intensity is desired.

As discussed in Section 1.0, glare and masking effects may impose an upper limit on DRL intensity. Therefore, it was considered desirable to evaluate both DRL daytime conspicuity <u>and</u> glare/masking effects in the 1000 to 2000 cd. range. As noted in Section 3.2.3 it has often been assumed that DRL lamps can be treated as point sources when seen from distances at which vehicle detection becomes important. If this is true, then luminous intensity in cd. is the appropriate physical correlate of conspicuity. If, on the other hand, DRL lamps function perceptually as extended sources, then area and luminance would become critical issues in conspicuity and DRL design. Resolution of this issue required an experimental design in which effects of area and luminance could be separated from those of intensity. Contrast between a vehicle and the background is a determinant of vehicle detection performance. The effect of contrast between a DRL lamp and the vehicle, however, has not been investigated.

DRL beam pattern is not an empirical issue but would be fundamental to development of a DRL concept. The empirical question is one of detection performance as a function of intensity (or perhaps area/luminance). If analyses of vehicle conflicts suggest that early detection at say 20 degrees from center is important, then a DRL lamp should produce sufficient intensity at that angle to provide conspicuity. The empirical data on detection versus intensity would be used to determine the necessary intensity at the angle in question but it would not be necessary to run tests at that particular angle to the vehicle. Therefore, detection tests were run with DRL lamps aimed directly at the observers and only central intensity was controlled.

DRL color effects constitute an experimental issue. Subjective evaluations by observers who judged the conspicuity of DRL lamps have often resulted in superiority of amber over clear lamps, but it has not been demonstrated that there is any such advantage when detection performance is used as the criterion.

Masking and glare effects may place an upper limit on the acceptable intensity of DRL. The most undesirable form of masking would appear to be masking of turn signals located close to DRL lamps. This effect has been demonstrated as discussed in Section 3.3.3., and the severity varies with distance. Masking of turn signals by DRL in the higher intensity ranges being studied here was considered an issue requiring evaluation.

Discomfort glare under low light levels was another experimental issue. Presumably, low beam headlamps used as DRL would be acceptable in this regard. The upper intensity level of 2000 cd. considered in the current study is well within the range allowed off-center for low beams by SAE Standard J579c so this effect was not expected to be severe for oncoming vehicles seen at some distance. High beam headlamps may constitute a glare source depending on the intensity used. For example, the Canadian DRL standard limits the high beam intensity to 7000 cd. at H-V. In any event, DRL on an oncoming vehicle will generally be seen at an angle because of roadway geometry. At short viewing distances, this angle may be considerable and the line of sight will be likely to lie outside of the central cone characteristic of high beams. At longer distances, the line of sight may be closer to the central cone but then the viewing distance may reduce the perceived degree of glare. For these reasons, it did not seem likely that 2000 cd. DRL lamps would produce discomfort glare in the oncoming vehicle case. This, however, is not necessarily a worst case. Glare produced via the rearview mirror may be more intense because the distance to a DRL equipped following vehicle may be only tens of feet. It is likely that the intensity at vertical angles above the horizontal will have to limited in developing a DRL design so as to preclude this source of glare. To provide a basis for such design, it was considered desirable to evaluate glare effects when the subject viewed DRL lamps in the 500 to 2000 cd. range via a rearview mirror.

Clearly, to perform experiments addressing the issues which have been discussed, a DRL lamp was required. It was not considered desirable, however, to test specific DRL implementations such as headlamps, turn signals, parking lamps, etc. Instead, the experimental approach called for use of a generic DRL lamp whose design parameters could be varied in different experimental treatments. The lamp chosen to meet the requirements of variable intensity, area, color, etc. was a Power model #817 accessory lamp. This has a luminous area very close to 100 sq. cm. and a height/width ratio of about 1/2 which made it convenient for control of area through use of one lamp, a masked lamp or two lamps mounted edge-to-edge. Varying the voltage supplied to the lamp controlled the intensity at H-V. Because it was economical to test several subjects at a time, it was desirable that the experimental lamp have a wide pattern in the H plane. The beam pattern for the experimental lamp is shown in Table 4-1. Photometric measurements on this lamp are expressed in Table 4-1 as a percent of the maximum intensity at the center.

Three experiments were performed which dealt with:

- vehicle peripheral detection under daylight conditions
- turn signal masking under daylight conditions
- rearview mirror glare under dawn/dusk conditions.

Table 4-1. Beam Pattern of Experimental DRL Lamp

DRL Intensity (Percent of Maximum)	Horizontal Angle (deg.)	Left					Right			
		45	20	10	5	V	5	10	20	45
Vertical Angle	5 deg. Up	4.5	5.0	4.5	4.5	4.5	4.5	4.5	3.5	2.5
	H	8.5	46.2	71.9	91.0	100.0	86.9	72.9	49.2	9.0
	5 deg. Down	3.0	4.0	4.5	5.0	5.5	5.0	4.5	3.5	2.5

5.0 VEHICLE DETECTION EXPERIMENT

The primary criterion on which effects of DRL design characteristics should be evaluated is driver performance in peripheral detection of an oncoming vehicle under daylight conditions. The vehicle detection experiment was performed to determine peripheral detection distance as a function of the following variables:

- DRL intensity at H-V
- DRL lamp area
- DRL separation - dual separated versus single center-mounted
- DRL lamp color - clear versus amber
- DRL background contrast
- ambient illumination level.

5.1 Method

The vehicle detection experiment was carried out on a two lane blacktop rural road which met selection criteria requiring a straight flat roadway section about one mile in length and approximately parallel to the apparent daily path of the sun, a safe subject location, and minimum traffic flow. Up to five subjects were run at one time. Subjects sat in portable chairs in a row and faced in a direction inclined at 15 degrees to the approach path of the experimental vehicle. Subjects faced a primary task stimulus consisting of a variable rate flashing light and were instructed to count flashes during a trial and to press a hand-held switch upon detecting an oncoming vehicle. Vehicle distance from a known starting point at detection was recorded automatically.

5.2 Independent Variables

Independent variable values used in the vehicle detection experiment are described below. DRL treatments resulting from orthogonal combination of intensity, separation and lamp size are shown in Figure 5-1.

5.2.1 DRL Lamp Intensity

All DRL treatments were implemented using Power model #817 accessory lamps which have a luminous area of approximately 100 sq. cm. and are capable of producing 3300 cd. at H-V at 13 volts DC. The use of this particular lamp does not mean that it is being recommended as a DRL implementation. The objective in the current study was evaluation of effects of generic DRL design parameters such as intensity, area and color. The intent was not to compare different specific lamps. The lamps used were selected entirely because they offered a convenient method of implementing the required levels of independent variables.

The intensities selected for the experiment were 0, 250, 500, 1000, and 2000 cd. at H-V. The 0 cd. level represents a control condition (i.e. no DRL). Lamp intensity was controlled by the

Intensity at HV (cd.)	Separation	Lamp Area (sq. cm.) 50	100	200
250	Single	250	250	125 125
	Dual Separated	250 250	250 250	125 125 125 125
500	Single	500	500	250 250
	Dual Separated	500 500	500 500	250 250 250 250
1000	Single	1000	1000	500 500
	Dual Separated	1000 1000	1000 1000	500 500 500 500
2000	Single	2000	2000	1000 1000
	Dual Separated	2000 2000	2000 2000	1000 1000 1000 1000

Figure 5-1. DRL Lamp Treatments

setting of a potentiometer to a specified voltage drop across the lamp circuit. A unique voltage drop was associated with each condition of DRL intensity, color, and lamp area. Required voltage drops specific to these lamp units and configurations were measured in the laboratory using DRL mounts and circuits, a Spectra Spotmeter™ model UBD-1 and associated probe and a 13 volt DC power supply. During data collection trials, the potentiometer was adjusted to the required voltage drop, as indicated by a DC volt meter mounted on the DRL control box. The car battery and alternator provided the power for the DRLs.

5.2.2 DRL Lamp Area

Lamp areas of 50, 100 and 200 sq. cm. were used in the vehicle detection experiment. The luminous area of the lamp unit used was 100 sq. cm. so this satisfied one level of area. The 50 sq. cm. area condition was implemented by use of a mask having a cut-out with a 50 sq. cm. center area as illustrated in Figure 5-1. The 200 sq. cm. area condition was implemented by mounting two lamps directly adjacent as shown in Figure 5-1. Each lamp was adjusted to one half of the nominal intensity under the 200 sq. cm. condition. For example, the 200 sq. cm. 2000 cd. combination was obtained using two lamps mounted together with each having a 100 sq. cm. area and 1000 cd. At the characteristic detection distances, this provided a stimulus equivalent to a 200 sq. cm. lamp having 2000 cd.

5.2.3 DRL Separation

Separation referred to two conditions - a single center mounted DRL lamp versus dual DRL lamps mounted with approximately the same separation as that between the vehicle turn signals. Separation conditions are illustrated in Figure 5-1. It should be kept in mind that one set of lamps was used in the single center mounted condition while two such sets were used in the dual condition so that the <u>total</u> intensity from all lamps under the dual condition was twice that under the corresponding single condition.

5.2.4 DRL Lamp Color

The DRL lamps were equipped with clear or amber lenses. These were changed between trials to control lamp color. Lenses were identical in all regards except color and levels of light transmittance.

5.2.5 DRL Background Contrast

Background plates for each DRL lamp position (left, center, right) were constructed. These were rectangular with a horizontal dimension of 18 inches and a vertical dimension of 12 inches. They provided a flat white or flat black background against which the DRL lamps contrasted. The test vehicle was dark blue. All chrome trim on the front of the test vehicle was masked with black plastic electrical tape to control possible spectral glare.

Trials were run during daylight hours from about 10 AM to 4 PM during the months of October and November. Ambient illumination was measured immediately following each trial using a Spectra model FC-200 photometer with a cosine corrected receptor. Ambient illumination could be controlled only grossly by selection of sunny, overcast, cloudy, etc. time periods. The observed range was from 14,000 lux representing heavy overcast to 94,000 lux under bright sunny conditions.

5.3 <u>Experimental Design</u>

The number of treatments yielded by orthogonal combination of all levels of the independent variables was 120. It was desirable to complete the trials for a group of subjects in one day and this number of treatments could not be accommodated. Therefore, subjects were divided into two groups and groups were assigned to treatment combinations in such a way that the three-way interaction of color, separation and contrast was confounded with differences between groups. This resulted in a one half replicate consisting of 60 trials per group. All main effects and two-way interactions were balanced with respect to group differences. The independent variable ambient illumination was not under experimental control. It was necessary to record this on each trial and to analyze the data via multiple regression.

Change in DRL color required changing lenses on all lamps and change in contrast level required changing background panels. These manipulations were somewhat time consuming so these variables were blocked. Color and contrast were held constant for a block of fifteen trials composed of three levels of lamp area and five levels of DRL intensity. Assignment of color/contrast combinations to trial blocks 1 to 4 was done using a latin square to counterbalance effects of these variables against practice effects.

Within a trial block, the 50 sq. cm. area condition was implemented using a mask to limit the lamp luminous area. This change required installation/removal of masks. Therefore, the five 50 sq. cm. trials within a block were grouped together. The order of presentation of the ten trials per block involving areas other than 50 sq. cm. was first randomized. The order of the 50 sq. cm. trials was randomized separately. The latter set was then inserted into the former at a randomly chosen position. Control of intensity, separation and areas other than 50 sq. cm. was done by switch settings. Levels of all independent variables per trial were specified by a run schedule.

5.4 <u>Test Site</u>

The vehicle detection experiment was carried out on Route 645 in Prince William County, Virginia. This is a two lane blacktop rural road which met selection criteria requiring a straight flat roadway section about one mile in length and approximately parallel to the apparent daily path of the sun, a safe subject location, and minimum traffic flow (on the order of three vehicles per hour). The test site geometry is shown in Figure 5-2. The DRL test vehicle approached along the straight

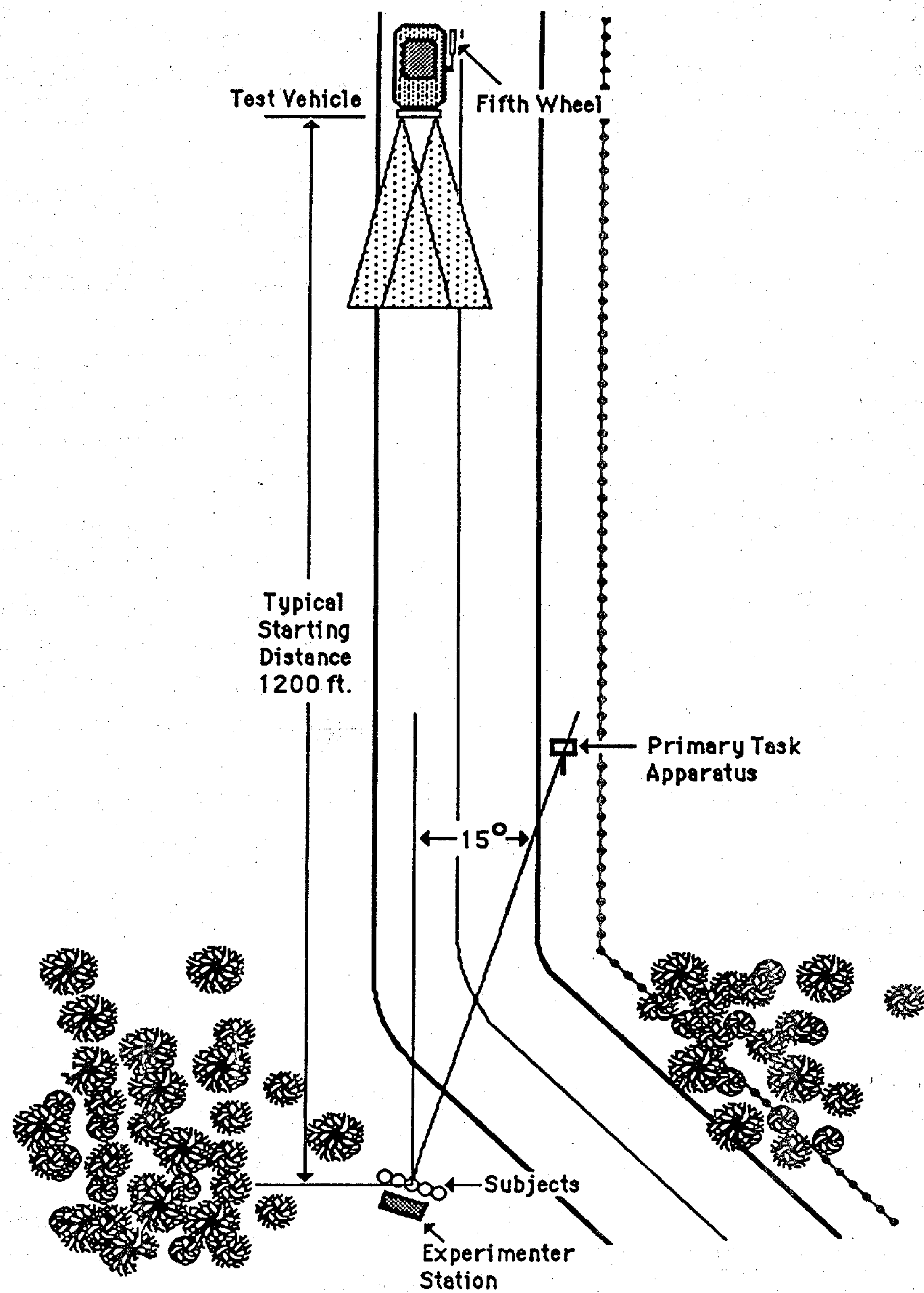

Figure 5-2. Vehicle Detection Experiment Test Site

roadway section. Subjects were located just off the road at a curve. Up to five subjects were run at one time. Subjects sat in portable chairs in a row and faced in a direction inclined at 15 degrees to the approach path of the experimental vehicle. The center subject position was aligned with the lane center line. The use of multiple subjects resulted in deviations from the nominal test vehicle peripheral angle (15 degrees) and the nominal DRL viewing angle (0 degrees). At characteristic detection distances, however, these deviations were small. The vehicle peripheral angle is the angle primary task - subject - center of vehicle. At a distance of 500 feet, which is less than the lowest mean detection distance obtained, the leftmost of five subjects would see the vehicle at a viewing angle of 16.5 degrees. The rightmost subject would see it at 13.5 degrees. Thus the maximum absolute error in peripheral viewing angle was about 1.5 degrees. The DRL angle is measured from the test vehicle and is the angle outermost subject - center mounted DRL lamp - center subject. The absolute value of this angle was about 0.4 degrees for both the leftmost and rightmost subjects. This was well within the center cone of the lamp used.

Subjects faced a primary task stimulus which consisted of a variable rate flashing light located as shown in Figure 5-2 and were instructed to count flashes during a trial and to press a hand-held switch upon detecting an oncoming vehicle. They were also instructed not to look away from the primary task display until told to do so by the experimenter. The subject location was shaded by trees so that subjects were not looking into the sun. The sun apparent path was approximately parallel to the straight roadway section.

The experimenter station was a table immediately behind the subjects. This contained the experimental apparatus, data forms, run schedules, etc. The experimenter could communicate with the DRL vehicle driver via two-way radio and could talk directly to the subjects.

5.5 Apparatus

Experimental apparatus in the vehicle detection experiment consisted of DRL control and distance measurement equipment mounted in and on the test vehicle, detection signal transmitting and primary task equipment and a Spectra FC-200 photometer located near the experimenter station, and CB radios for communications.

5.5.1 DRL Test Vehicle

A 1984 Ford Escort, provided by NHTSA, served as the test vehicle and is shown in Figure 5-3. This car was modified by the addition of six lights mounted on a bar attached to the front bumper of the vehicle. These consisted of two vertically stacked units at the right, center, and left positions of the automobile as indicated in Figures 5-1 and 5-3. Design and mounting details of the light bar are shown in Figure 5-4.

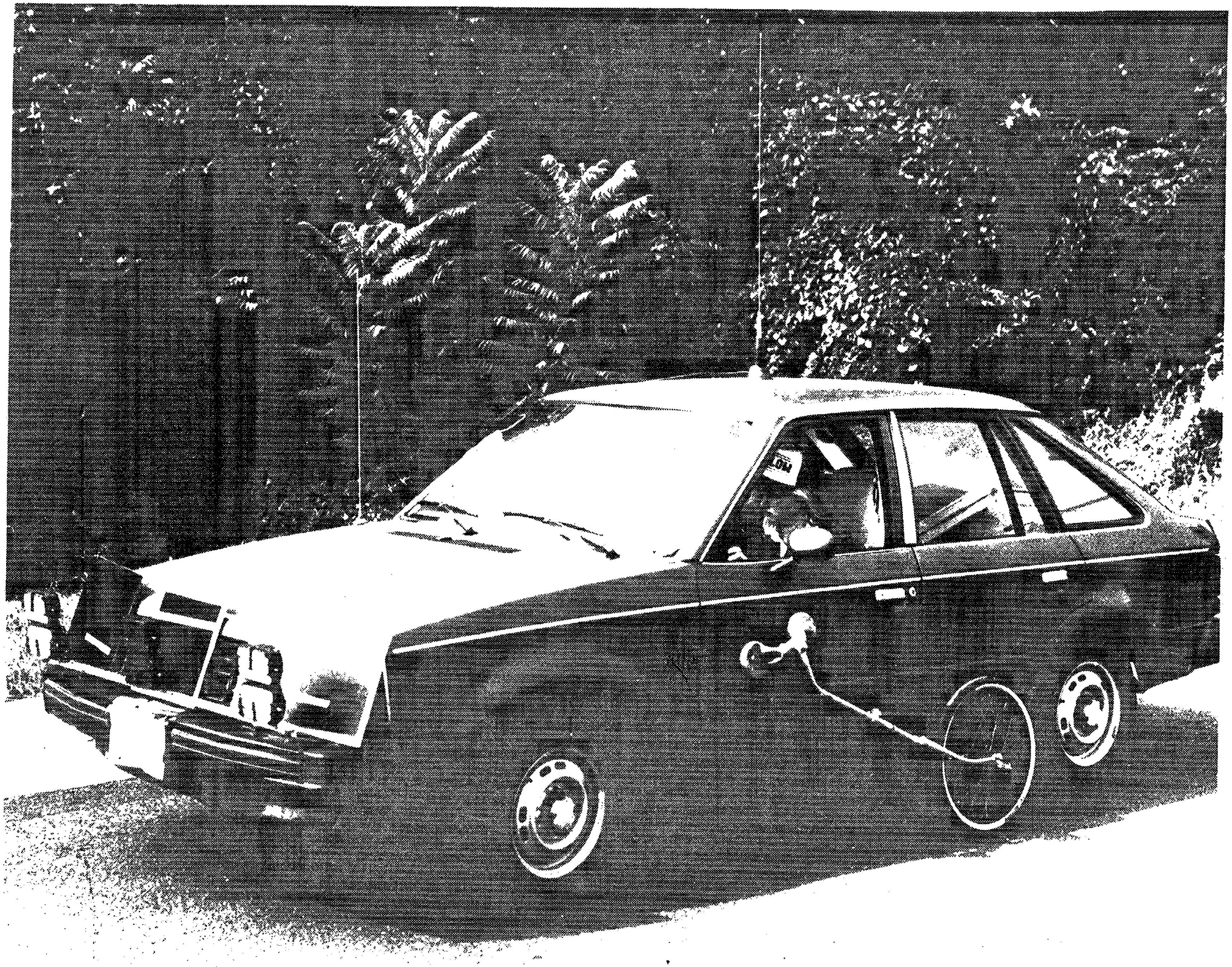

Figure 5-3. Test Vehicle

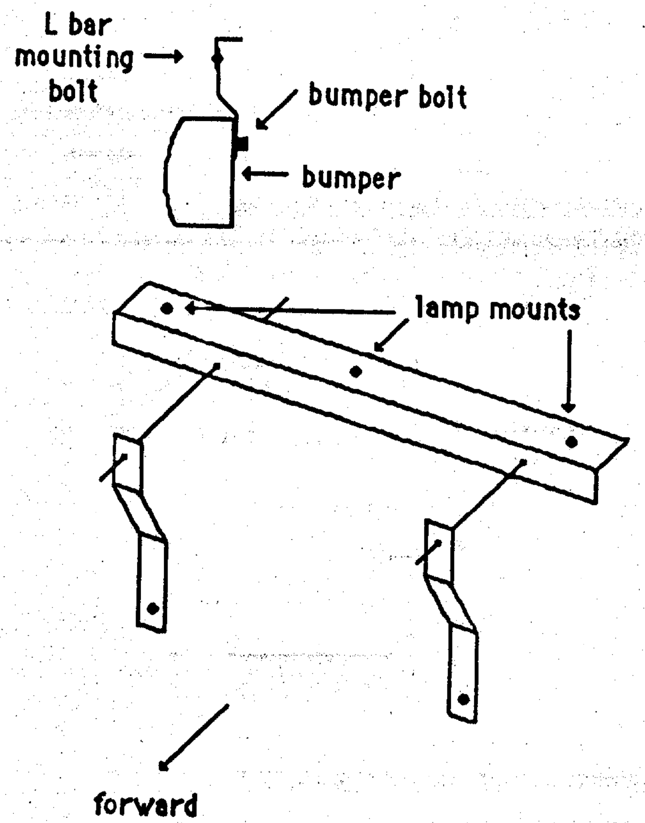

Figure 5-4. DRL Light Bar Details

The configuration and intensity of the lights was controlled by the driver of the test vehicle using a control box mounted on the dashboard. The DRL control circuit is shown in Figure 5-5. Switches were provided to allow selection of various sets of lamps. The 50 sq. cm. condition required the use of a mask inserted into the lower lamp of each group (see figure 5-1). Different lenses were used for clear and amber light color conditions. and required a lens change to alternat between these conditions. Lamp intensity was controlled by the setting of a variable resistor to a specified voltage drop across the lamp circuit. Prior to a data collection trial, the potentiometer was adjusted to the required voltage drop as indicated by a DC voltmeter mounted on the DRL control box. The car battery and alternator provided the power for the DRLs.

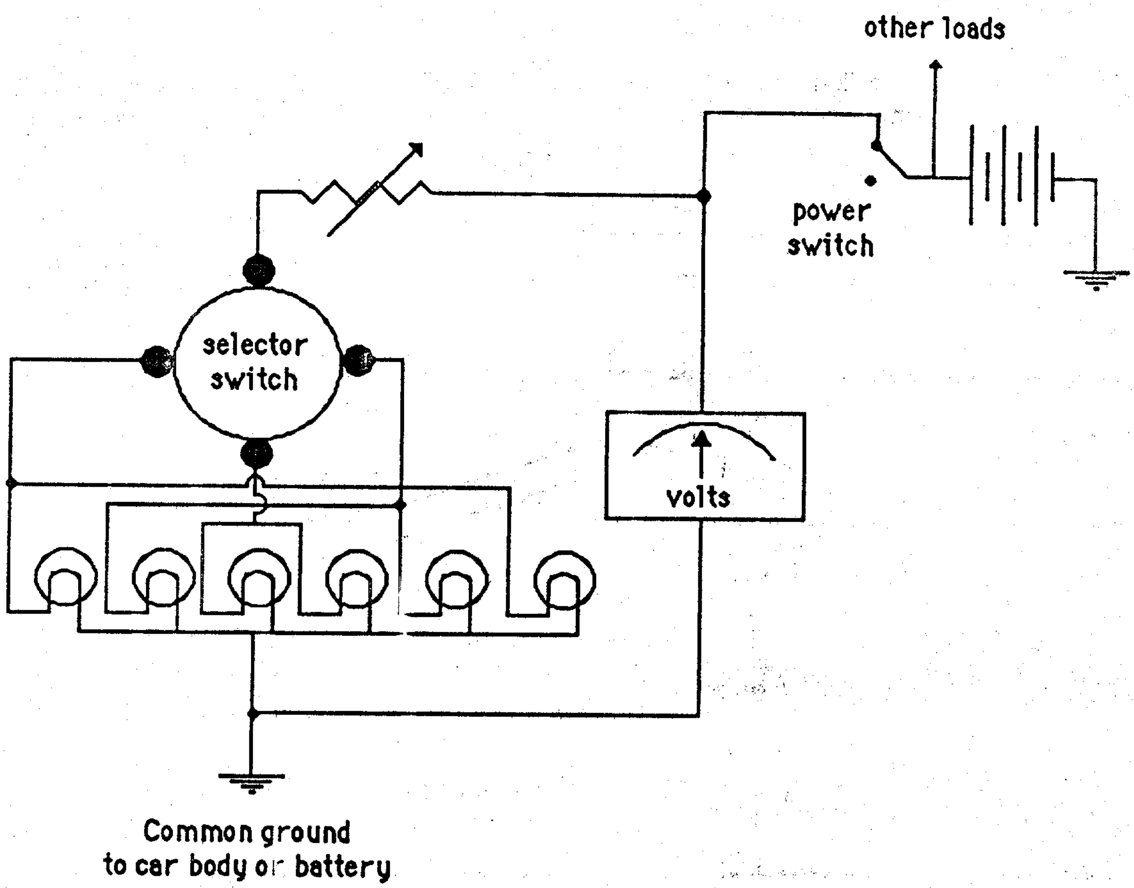

Figure 5-5. DRL Lamp Control Circuit

5.5.2 Experimenter Station

Primary Task Control Equipment - A control box for the primary task display was located at the experimenter station. This was used to turn the display on and off and to control the flash rate. The primary task control box is illustrated in Figure 5-6.

Vehicle Detection Handswitches and Circuits. Each subject was provided with a small pushbutton handswitch which was used to signal test car detection. Momentary depression of the pushbutton in each handswitch activated two separate circuits. The first illuminated one of five lights (each associated with a specific subject) at the experimenter station, indicating vehicle detection for each subject. This light remained on until reset by the experimenter at the end of each trial. The second circuit activated the radio transmitter to send a signal to distance measurement equipment mounted in the test vehicle. The subject response box is shown in Figure 5-6.

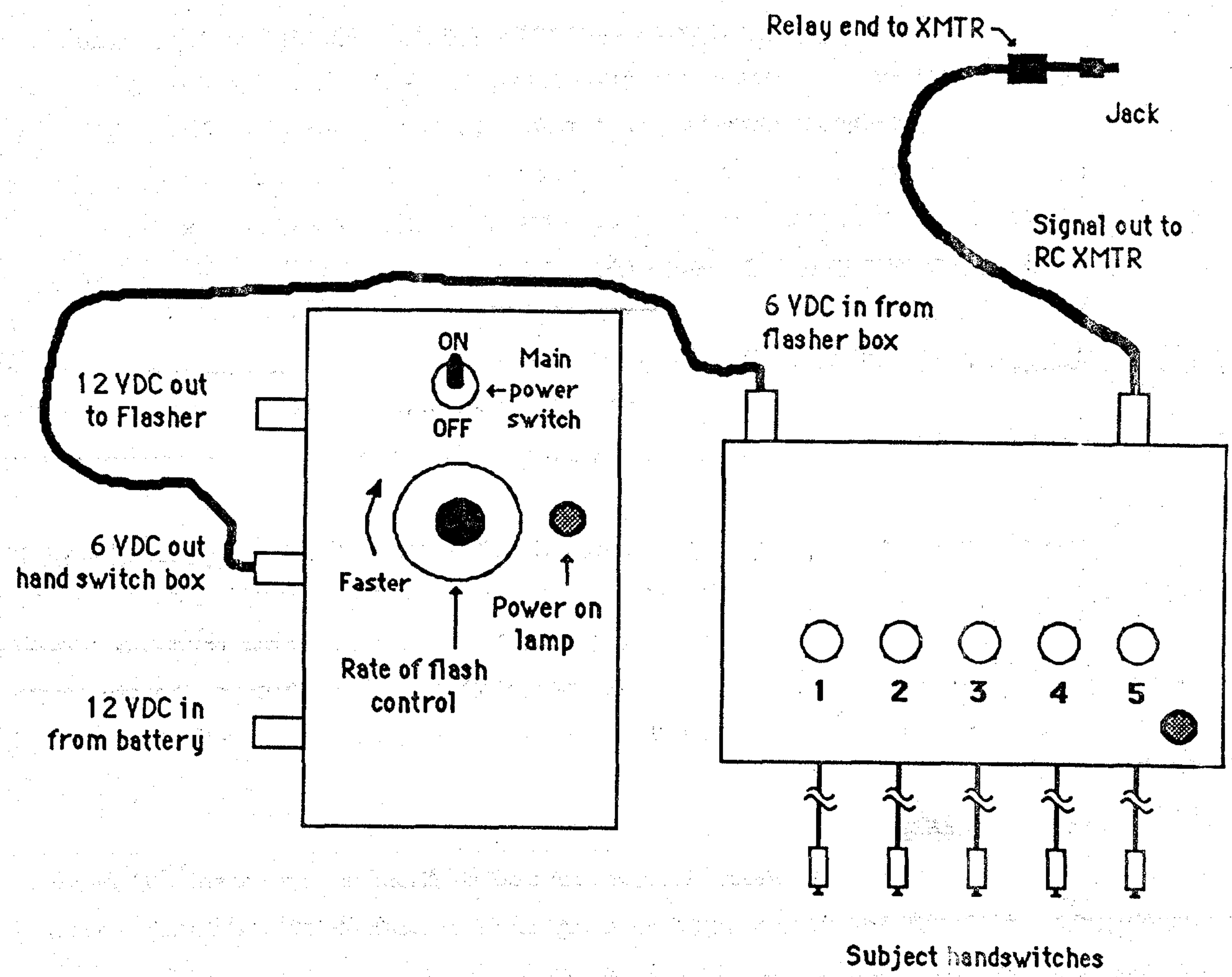

Figure 5-6. Primary Task Control and Subject Response Equipment Located at Experimenter Station

Photometer - A Spectra model FC-200 photometer with a cosine corrected illuminance probe was used to measure ambient lighting conditions at the time of each trial. Measurements were indicated in lux, with a potential range of 0 to 300000. The photometer was located in the vicinity of the experimenter station so that it received direct sunlight.

5.5.3 Travel Distance Measurement

Distance traveled by the test vehicle from a standard start point to the point of vehicle detection by the subject was determined using a measurement system procured from the Automotive Features Company. A fifth wheel was mounted on the driver side door of the test vehicle by means of suction cups. Four magnets mounted on the hub of the wheel reported to a reed switch mounted outboard of the wheel axle. While the vehicle moved, the reed switch reported each passage of the magnets to a Cygnus Automobile Performance Computer and printer. The computer and printer were positioned on the front passenger seat of the vehicle, next to the driver. The computer was calibrated to count reed switch pulses and to continuously compute and display distance traveled in feet. Computed distance was accurate to approximately three feet over distances up to one mile. The on-board printer circuitry continuously monitored the elapsed distance display, and upon receiving a pulse from a radio controlled relay, captured and printed elapsed distance data

A relay, powered by a remote control radio receiver, was used as the control switch for the printer. The radio receiver and antenna were mounted on the front windshield of the test car. The receiver was a Challenger 2000 hobbyist radio receiver and servo. The unit was modified to bypass the servo, using the servo motor power to actuate the coil in the relay switch. The receiver was actuated by a radio transmitter located near the subjects station when a subject reported vehicle detection by pressing a hand-held switch.

The transmitter was located at the experimenter station. Upon handswitch closure by a subject, a 250 millisecond timing circuit operated a relay which provided power to the radio remote control transmitter. The signal generated by the transmitter actuated the receiver and relay unit located in the test car, which in turn actuated the data printer so that travel distance was printed automatically whenever a subject pressed the handswitch. The handswitch, transmitter and receiver/printer circuits are shown in Figure 5-7.

5.5.3 Primary Task Display

During each detection trial, subjects were required to attend to and count the pulses of a flashing light. This light was located approximately 150 feet from the subjects and 15 degrees to the right of the approach path of the test car as shown in Figure 5-2. The "on" duration of the light was approximately 0.5 second. The "off" duration was under the control of the experimenter, with a continuous range of one flash every 2 to 15 seconds. At the end of each trial, subjects reported total flashes counted.

5.5.4 Radio Communications

Communications between the experimenter and test vehicle driver were provided by means of a CB radio in the test vehicle and a hand held transceiver at the experimenter station.

5.6 Procedures

Subjects reported to the Carlow office in Merrifield, VA. Vision tests were given and administrative details were completed. Subjects were then transported to the test site. A standard set of instructions was read, explaining the procedure, and two practice trials were administered. During this time any questions were answered by the experimenter. Data collection trials were then administered in four blocks of fifteen trials each. A break was allowed between blocks.

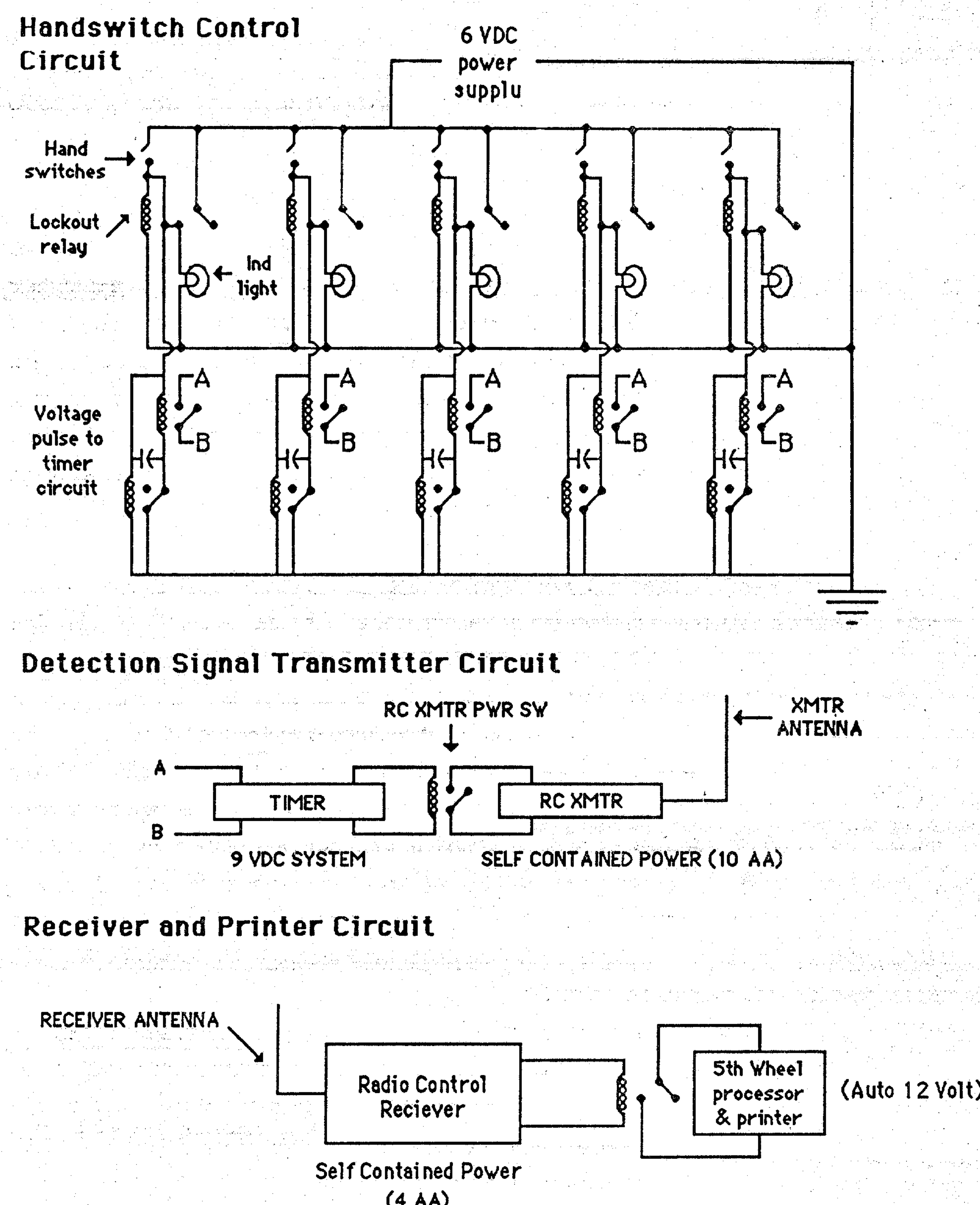

Figure 5-7. Travel Distance Measurement Circuits

5.6.1 Vision Tests

Two vision tests were applied to all subjects. Visual acuity was tested using a standard Snellen chart. Contrast sensitivity was tested using the VISTECH Consultants Incorporated VCTS 6500 test.

5.6.2 Instructions to Subjects

A standard set of instructions was read to each group of subjects after arrival at the test site. These instructions directed the subjects to attend to the primary task apparatus and to count signals (flashes) when told to by the experimenter. It was repeatedly stressed that subjects were to look directly at the secondary task apparatus until the experimenter asked them to report the number of flashes. Subjects were informed that at some time during the trial, a vehicle might approach on the roadway and that if they detected this, to press a hand held switch whose function was then demonstrated. They were told that total certainty of a detection was not necessary but to respond when certain enough that they would look toward the detected vehicle if they were driving. Following the written instructions, the experimenter answered any questions.

5.6.3 Trial Procedure

Treatments in the vehicle detection experiment were the 120 combinations of levels of the independent variables. These were identified in the run schedule by the integers 1 to 120. The experimenter consulted the run schedule to determine the next trial and treatment number. This was communicated to the test vehicle driver when the test vehicle was stopped at the experimenter station following the last run. The driver wrote the next trial number and treatment number on the printer tape. The test vehicle was then driven to one of several turn-offs from the roadway. Most runs were made with a starting distance of 1200 ft. During pilot testing , it was noted that with DRL intensity of 2000 cd. and low ambient illumination, detection was sometimes reported at distances beyond 1200 ft. Therefore, runs under these conditions were made using a starting distance of 1800 ft. The experimenter and test car driver determined which distance to use based on the DRL intensity for the next trial and on the last photometer reading. The experimenter then recorded the start distance selected on a data sheet.

The test vehicle was driven into one of two turn-offs from the roadway where the front end of the vehicle was out of the view of subjects. The driver consulted a treatment table using the treatment number. This indicated levels of independent variables for each treatment and switch settings necessary to obtain these. For the first trial in each block, the DRL lamp lenses were installed to obtain the correct color (amber or clear) and the background plates were installed to obtain the correct contrast (black or white). If the lamp area for the next trial was 50 sq. cm., then masks were installed on the lower lamps.

Inside the vehicle, the driver set switches on the DRL control box for area and separation according to the treatment table. Next the variable resistor was adjusted with the engine above idle speed so that the correct voltage across the DRL lamps was obtained. The voltage necessary for the desired intensity was given as a function of area and color in the treatment table. The DRL lamps were then turned off. The driver backed out into the roadway and positioned the test vehicle in the center of the lane at a measured starting point painted on the road. He/she lowered the fifth wheel into contact with the roadway, reset the distance measuring equipment and reported "ready" to the experimenter via radio.

The experimenter reset the detection handswitch circuit if this had not been done previously, set the primary task flash rate, turned on the primary task apparatus, instructed the subjects to attend to the primary task and instructed the driver to start. The driver then turned on the DRL lamps if the trial did not involve zero intensity and accelerated the vehicle rapidly to 25 mph. This speed and a vehicle heading directly toward the subjects was maintained throughout the approach. During the run, the experimenter monitored lamps on the detection circuit box which corresponded to the different subjects. When a given subject pressed the handswitch, the corresponding lamp illuminated. This allowed the experimenter to record on a data sheet the order in which the subjects responded. Ties or near-simultaneous switch presses were also noted on the data sheet. As detection responses occurred during the run, the handswitch circuit sent pulses to the transmitter and these were received by the receiver on the vehicle and sent to the computer which then printed out the currently sampled travel distance.

After the test vehicle had passed the subject position, the driver turned off the DRL lamps, stopped the vehicle, raised the fifth wheel, turned the vehicle around and drove to the vicinity of the experimenter station. While this was being done, the experimenter read the photometer and recorded the ambient illumination. The experimenter and driver conferred on the trial results to confirm that all detection responses had been recorded. The main requirement for this arose because of tied responses. On some occasions, two or more subjects responded within the cycle time of the computer. This produced fewer printed lines than there were subjects. By using tie or near-tie information recorded during the run, the experimenter and driver were able to correctly assign subject numbers to printed lines in cases of ties.

The experimenter then determined the next trial and treatment and the trial procedure was repeated until a trial block was completed. Printer tapes and experimenter data sheets were stored together for later calculation of detection distance by subtracting the recorded vehicle travel distance from the starting distance.

5.7 Subjects

Eighteen subjects were used in the vehicle detection experiment. They included Carlow employees, persons recruited for the experiment by Carlow employees and students at George

Mason University recruited through advertisements at the university. All subjects were licensed drivers, had normal corrected or uncorrected acuity and fell within the normal range on the contrast sensitivity test. Subjects included nine males and nine females having the following age distribution:

Subject Age	Number
< 25	2
25 -35	6
> 35	10

Carlow personnel were paid at their hourly rates and other subjects were paid a fixed amount for participation in the experiment.

5.8 Results

Four groups of subjects were run in the detection distance experiment. Group 1 completed only the first two trial blocks due to equipment failure and deteriorating weather conditions. It was planned to reassemble this group later but this proved not to be feasible. Groups 2 through 4 completed all four trial blocks. The data collection effort resulted in 827 usable trials across all groups. Ambient illumination varied between and within days so that the four groups experienced different levels of ambient illumination. The numbers of subjects and trials and mean, minimum and maximum ambient illumination by group are shown in Table 5-1.

Table 5-1. Subject Groups

Group	Number of Subjects	Number of Trials	Ambient Illumination (lux)		
			Minimum	Mean	Maximum
1	5	147	14000	30027	60000
2	4	204	25000	44333	82000
3	5	260	19000	54508	94000
4	4	216	19000	32556	70000
Total	18	827	14000	41912	94000

5.8.1 Regression Analysis Using All Independent Variables

When all six independent variables were considered including ambient illumination, the data matrix did not represent a balanced experimental design because ambient illumination varied randomly from trial to trial. Therefore, to include ambient illumination in the analysis, it was necessary to employ regression analysis. This technique allows for intercorrelations among independent variables, if any, in a matrix having missing data. The data were subjected to multiple regression analysis using the following variable coding:

- Lamp area - 50, 100 or 200 sq. cm.
- Background
  - 0 = black
  - 1 = white
- Color
  - 0 = clear
  - 1 = amber
- Separation
  - 0 = single center mounted
  - 1 = dual
- DRL intensity - 0, 250, 500, 1000, or 2000 cd.
- Ambient illumination - 14000 to 94000 lux.

The results of this analysis are shown in Table 5-2. The multiple correlation coefficient was found to be .269 with all independent variables listed above included in the model. The regression model was:

$$\text{Distance} = \text{Constant} + \sum_{k=1}^{6} C_k \cdot X_k$$

where the C_k are regression coefficients and the X_k are independent variables (area, background, color, etc.). The regression coefficients are given in Table 5-2 in both raw score and standardized form. The raw score coefficients are least squares estimates of the regression coefficients in the above equation using the variable coding shown above. The standardized coefficient values would only be applicable if all independent and dependent variables were converted to standardized form. The analysis of variance portion of Table 5-2 presents a test of significance of the entire regression

Table 5-2. Multiple Regression Analysis of Vehicle Detection Distance Using Data From Subject Groups 1 to 4

Multiple Regression of Detection Distance

N = 827
R = .269

Independent Variable	Raw Score Coefficient	Standardized Coefficient	T Statistic	Alpha Level
Constant	691.887	0.000	24.771	<0.001
Size	0.156	0.045	1.338	0.181
Background	-25.522	-0.059	-1.744	0.082
Color	-92.982	-0.215	-6.373	<0.001
Separation	24.847	0.058	1.697	0.090
Intensity	0.033	0.106	3.158	0.002
Ambient	-0.001	-0.700	-2.078	0.038

Analysis of Variance

Source	Sum of Squares	Degrees of Freedom	F-Ratio	Alpha Level
Regression	2772926.009	6	10.673	<0.001
Residual	.355056 E+08	820	——	——

relationship. The null hypothesis is that in the population the variance accounted for by regression on the independent variables is zero. This hypothesis may be rejected at the .001 level. The T statistics shown in Table 5-2 provide significance tests of the difference of each coefficient from zero.

The regression analysis was performed as an approach to determining the significance levels of effects of the independent variables rather than because of interest in using the regression equation. If one were interested in using the regression equation to predict detection distance for a given DRL concept, the authors would suggest incorporating into the equation only those variables which reached statistical significance as indicated by the T test values and alpha levels in Table 5-2.

DRL intensity was found to be significant at the .002 level and ambient illumination at the .05 level. Color is shown to be significant beyond the .001 level in Table 5.2 but this effect is almost surely due to confounding of color effects with subject differences. Very little within-subject information on clear versus amber lamps was available from group 1 because only the first two trial blocks were completed and the blocking scheme was such that these trials involved only the clear color condition. Large between-subject differences were apparent in the data and group 1 was characterized by greater average detection distances than were the other three groups. Mean detection distance is shown in Figure 5 8 for all data as a function of DRL intensity, group and ambient illumination. Ambient illumination was dichotomized as high or low using the mean value of 41912 lux. The Low and High legends in Figure 5-8 refer to ambient illumination below 41912 lux and above 41912 lux respectively. There are some missing points in Figure 5-8 because groups 1 and 4 were run on days having lower illumination levels than were groups 2 and 3. This is reflected in the mean illumination levels shown in Table 5-1. For group 1, no high illumination data were available for DRL intensities of 500 or 1000 cd. For group 4, no high illumination data were available for the 2000 cd. condition. Nevertheless, it is clear from Figure 5-8 that detection distances obtained from group 1 were generally considerably greater than were those for other groups.

Group 1 completed only the first two trial blocks which were run using clear lenses and two trials of the third block using amber lenses. Numbers of trials and mean detection distances are shown for group 1 and for groups 2-4 in Table 5-3. Group 1 contributed 138 trials to the clear color condition and only 9 trials to the amber condition. When data for group 1 were ignored and mean detection distances under the two color conditions were calculated using data from groups 2 through 4, these were found to be very nearly identical so the apparent color effect is clearly the result of individual between-group differences which were confounded with lamp color.

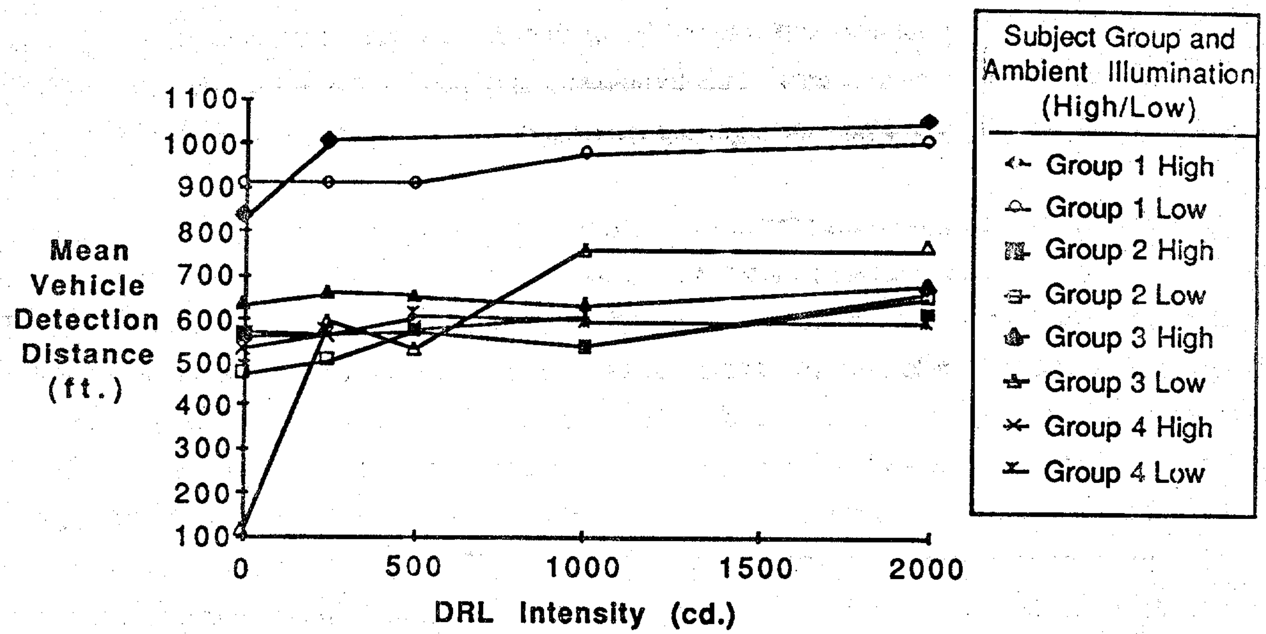

Figure 5-8. Mean Vehicle Detection Distance as a Function of DRL Intensity, Ambient Illumination and Subject Group - Regression Analysis Data

Table 5-3. Mean Vehicle Detection Distance as a Function of DRL Color and Subject Groups - Regression Analysis Data

DRL Color		Group 1	Groups 2-4	Total
Clear	N:	138	319	457
	Mean:	942	598	701
Amber	N:	9	361	370
	Mean	946	598	607

The effect of primary interest is that of DRL intensity and the interaction of this with ambient illumination. Mean vehicle detection distance as a function of DRL intensity is shown in Table 5-4 for low and high ambient illumination levels and collapsed across illumination levels. The Table 5-4 data are plotted in Figure 5-9. The main effect of DRL intensity does not show increases in detection distance below 500 cd. From 500 to 2000 cd., however, a regular increase in detection distance appears. The data suggest that the DRL intensity effect is more pronounced for low ambient illumination than for high.

Table 5-4. Mean Vehicle Detection Distance as a Function of DRL Intensity and Ambient Illumination - Regression Analysis Data From Subject Groups 1-4

	Ambient Illumination (lux)					
	Low		High		Total	
DRL Intensity (cd.)	Number of Cases	Mean Distance (ft.)	Number of Cases	Mean Distance (ft.)	Number of Cases	Mean Distance (ft.)
0	58	656.1	51	643.7	109	650.3
250	114	617.0	64	688.0	178	642.5
500	108	649.0	72	613.8	180	634.9
1000	75	754.9	105	589.6	180	658.5
2000	112	709.9	68	699.2	180	705.9
Total	467	673.7	360	640.3	827	659.2

The vehicle detection data were found to exhibit considerable between-subject and within-subject variability. In some cases, means may have been influenced by a few extreme scores. An analysis of DRL effects was carried out in which an attempt was made to reduce effects of extreme values and between-subject variability. First, the highest and lowest distance values were deleted from each treatment condition composed of one level each of lamp area, background, color, separation and DRL intensity. Second, detection distances were converted to <u>improvement scores</u> on a subject-by subject basis. The improvement score was defined as:

$$\text{Improvement}_{ijk} = \text{Distance}_{ijk} - \text{Mean Distance}_{i0}$$

The subscript i refers to subjects, the subscript j refers to DRL intensity conditions and the subscript k refers to all combinations of the remaining variables. Each detection distance score in the matrix was converted to an improvement score by subtracting from it the mean detection distance at zero DRL intensity for the subject in question. Mean improvement scores were then calculated as a function of DRL intensity and ambient illumination (high vs. low). These are shown in Figure 5-10. The origin in Figure 5-10 represents the grand mean detection distance at 0 DRL intensity as zero. If there were no effect of ambient illumination, the mean improvement score at zero DRL intensity would be zero. Improvement scores for some of the low ambient illumination data points were negative because they involved mean detection distances which were less than the grand mean at the intensity level in question. The vertical positions of the curves reflect the main effect of ambient illumination. The improvement score data suggest that detection performance improves regularly with DRL intensity under low illumination (as defined here). Under high illumination, however, DRL intensities in the range from 250 to 1000 cd. had a less pronounced effect.

The magnitude of the difference in improvement score between the extremes of DRL intensity (0 vs. 2000 cd.) was approximately 80 feet. At 55 mph, this distance corresponds to about one second of travel time and at 30 mph to nearly two seconds. It is difficult to transform these distance/time relationships into safety improvement values but it can be noted, that a second is a fairly long time in relation to human latencies and reaction times. If the safety benefit of 2000 cd. DRL as compared to no DRL is a reduction on the order of the number of crashes which could have been prevented had an oncoming vehicle been detected one to two seconds sooner, then this benefit may be considerable.

5.8.2 Analysis of Covariance Excluding Zero Intensity Treatments

The data and results of section 5.8.1 are regarded as adequately describing main effects of DRL intensity and joint effects of DRL intensity and ambient illumination. The regression technique does not readily address joint effects of independent variables. Therefore, an analysis of covariance was conducted on a subset of the data with ambient illumination as the covariate. The detection distance data were transformed for this analysis by subtraction of a term involving the regression coefficient of ambient illumination and the mean level of ambient illumination.

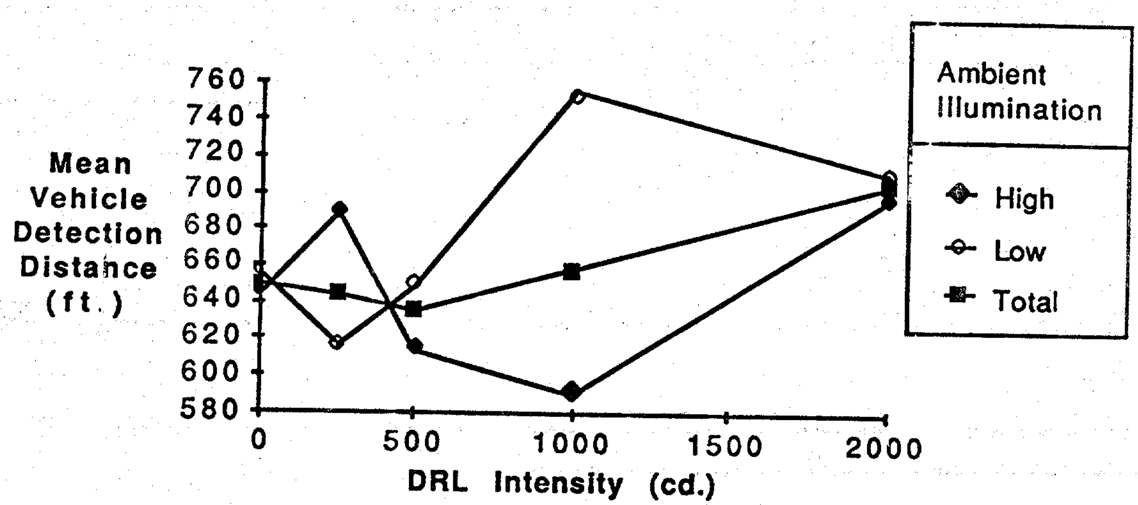

Figure 5-9. Mean Vehicle Detection Distance as a Function of DRL Intensity and Ambient Illumination - Regression Analysis Data From Subject Groups 1-4

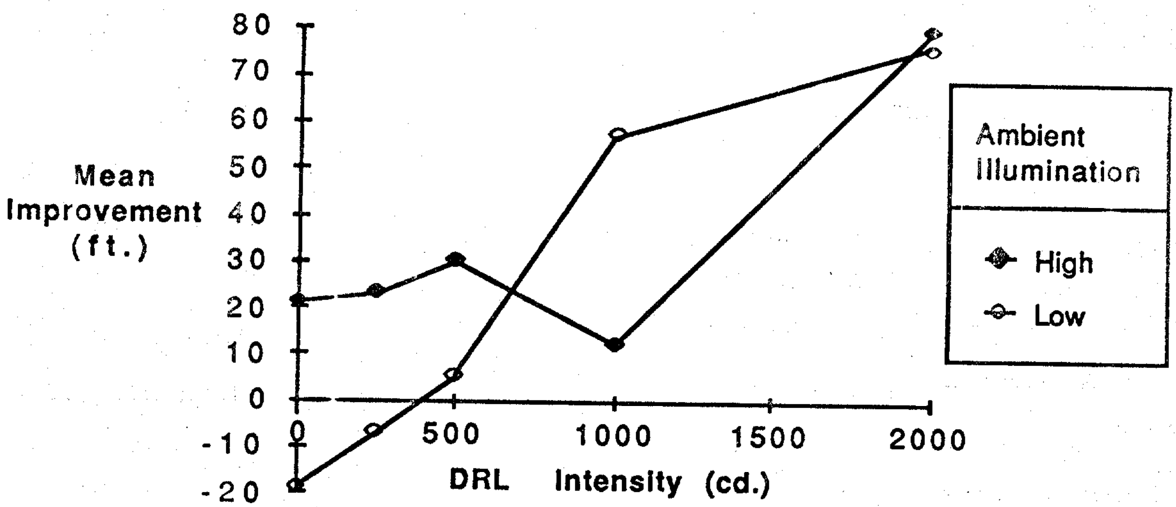

Figure 5-10. Mean Vehicle Detection Distance Improvement as a Function of DRL Intensity and Ambient Illumination - Regression Analysis Data From Subject Groups 1-4

There is an additional problem in directly interpreting the significance of independent variables other than DRL intensity in the data from section 5.8.1. This involves the zero intensity (no DRL) condition. When the DRL intensity main effect is considered, it is appropriate to include the no DRL data because zero intensity represents a logical point on the intensity curve. When other independent variables are considered, however, inclusion of no DRL data may result in under-estimation of the effects of these. Consider lamp area, for example. The classification of data according to lamp area really makes sense only when the lamps are turned on. The calculation of treatment means for different lamp areas will involve a certain number of no DRL trials if all the data points are used. It seems highly unlikely that area could influence performance for cases in which the DRL lamp was turned off. Collapsing across the entire data matrix at each particular level of area and including zero intensity DRL data points would appear likely to suppress true effects of area or other independent variables. For these reasons, the zero DRL intensity data were excluded from the analysis of covariance. The analysis was applied to 718 data points for which the DRL lamps were turned on at some intensity level.

The analysis of covariance consists of analysis of variance applied to scores after subtraction of the regression effect of the covariate (Winer, 1962). In the 718 DRL data points, the mean detection distance was 661 feet, the mean ambient illumination was 41728 lux and the regression coefficient for the effect of ambient illumination was -.001. Therefore, detection distance adjusted to remove the general effect of ambient illumination was calculated as follows where Y_{adj} is adjusted detection distance, **Y** is measured detection distance and **X** is measured ambient illumination in lux:

$$Y_{adj} = Y - [-.001 \times (X - 41728)] \qquad \text{or:}$$

$$Y_{adj} = Y + .001\ X - 41.728$$

Y_{adj} is essentially the residual error for the regression relationship between detection distance and ambient illumination. The analysis of covariance of this measure is shown in Table 5-5. Only main effects and two-way interaction variances were calculated. Missing data would have caused difficulties in calculating higher order interactions and most of the three-way and higher interactions were confounded with differences between subjects due to the fractional replication experimental design. Assuming that these higher order interactions are negligible in the population, interaction terms other than main effects and two-way interactions were pooled to provide a general error term. The analysis shown in Table 5-5 is probably somewhat more powerful than the regression analysis of Table 5-2 because of the removal of the between-subjects main effects. Means were calculated both with and without group 1 because the confounding of group 1 effects with those of DRL color must be examined in order to interpret effects involving color.

Table 5-5. Analysis of Covariance of Adjusted Vehicle Detection Distance From Non-Zero Intensity Treatments and Subject Groups 1-4

Source	df	SS	MS	F	Alpha
DRL Intensity (I)	3	57.590	19.197	10.75	0.001
Lamp Area (A)	2	6.762	3.381	1.89	0.250
Lamp Color (C)	1	125.776	125.776	70.41	0.001
Background (B)	1	0.535	0.535	0.30	——
Separation (D)	1	12.859	12.859	7.20	0.001
Subjects (S)	17	1583.542	93.150	——	——
I x A	6	18.626	3.104	1.74	0.250
I x C	3	13.428	4.476	2.51	0.100
I x B	3	9.806	3.269	1.83	0.250
I x D	3	5.319	1.773	0.99	——
A x C	2	67.497	33.748	18.89	0.001
A x B	2	10.262	5.131	2.87	0.100
A x D	2	3.935	1.968	1.10	>0.250
C x B	1	8.606	8.606	4.82	0.050
C x D	1	1.676	1.676	0.94	——
B x D	1	39.868	39.868	22.32	0.001
Residual (Error)	668	1193.338	1.786	——	——
Total	717	3159.425	——	——	——

Tests of main effects in Table 5-5 were found to be in substantial agreement with those of Table 5-2. DRL intensity and lamp color were found to be highly significant in both analyses. Lamp separation which exceeded the .10 level in the regression analysis was found to reach the .001 level in the analysis of covariance.

The DRL intensity main effect has already been illustrated in Figure 5-9. The separation (single vs. dual) main effect was due to the fact that the mean detection distance for the single lamp configuration was found to be 647 feet while that for the dual separated condition was 674 feet. Thus a difference of about 27 feet in mean detection distance is attributable to the separation factor.

The significant effect of DRL color in Table 5-5 was the result of confounding of between-subject differences with color due to the incomplete group 1 data as discussed in Section 5.8.1. This is illustrated in Table 5-6. With the zero DRL intensity treatment data deleted, group 1 contributed 108 trials to the clear condition data but only 4 trials to the amber condition data. When the amber-clear comparison was made using only data from groups 2-4, the mean detection distances varied by only a few feet.

Table 5-6. Mean Adjusted Detection Distance as a Function of DRL Color and Subject Groups - Analysis of Covariance Data From Non-Zero Intensity Treatments

DRL Color		Group 1	Groups 2-4	Total
Clear	N:	108	295	403
	Mean:	950	605	698
Amber	N:	4	311	315
	Mean	909	609	613

Among the two-way interactions tested in the analysis of covariance, the following were found to reach significant alpha levels: area x color (.001), color x background (.05) and background x separation (.001). The interaction of area and color is illustrated in Figure 5-11. Because color effects were influenced by the subject differences involving group 1, the data have been plotted with and without group 1. Exclusion of group 1 did not greatly change the amber curve in Figure 5-11. The clear curve, however, was strongly influenced by the data trials contributed by group 1 and interpretation of the area x color interaction is best done using the group 2-4 data. The right-hand graph in Figure 5-11 shows that amber lamps resulted in greater detection distances for

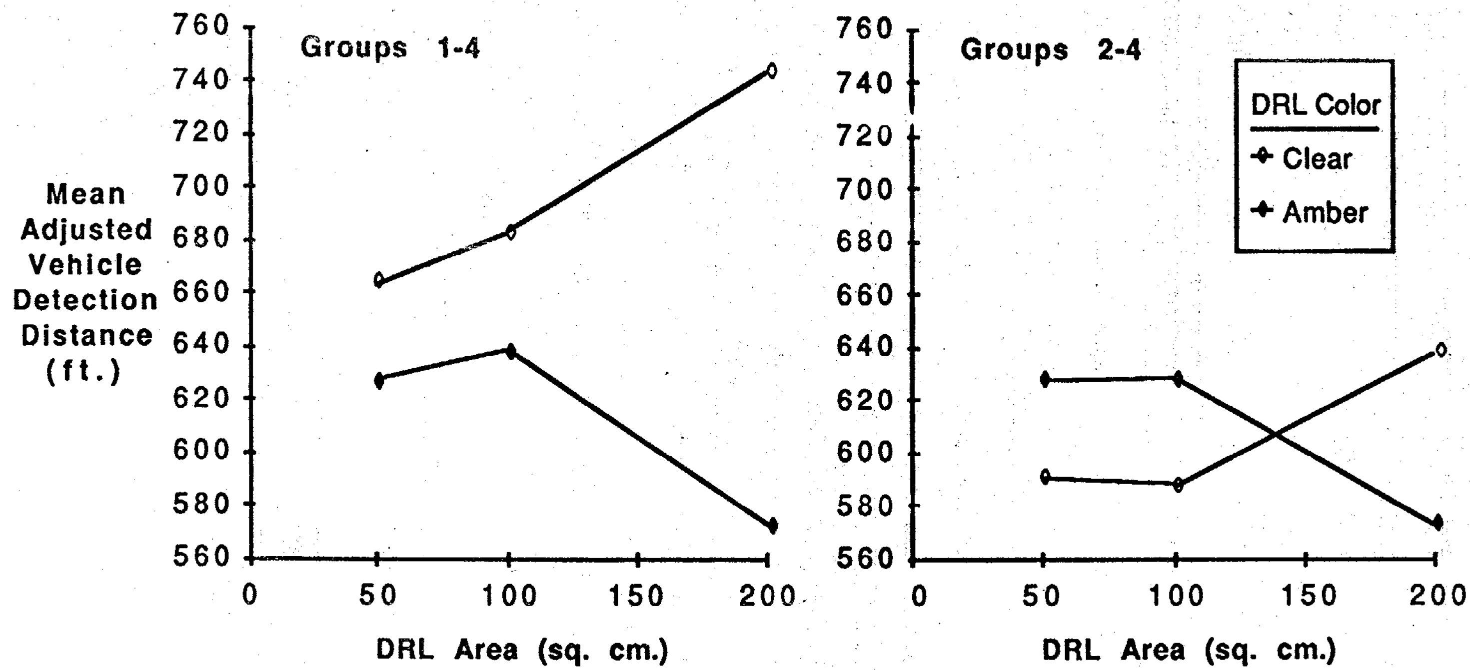

Figure 5-11. Mean Adjusted Vehicle Detection Distance as a Function of DRL Area, Color and Subject Groups - Analysis of Covariance Data From Non-Zero Intensity Treatments

the two smaller lamp areas but that this effect was reversed for lamps of 200 sq. cm. The 100 sq. cm. area corresponds approximately to that of a typical turn signal or fog lamp while the 200 sq. cm. area is characteristic of a single headlamp. The figure 5-11 data suggest that amber is preferable for dedicated DRL, turn signals or fog lamps used as DRL in the 100 sq. cm. range or smaller. The apparent diference between amber and clear lamps for lamp areas of 50 and 100 sq. cm. was tested using Scheffe's test. For the 50 and 100 sq. cm. areas only, the mean adjusted detection distance for amber lamps was found to be 628 feet while the corresponding value for the clear lamp condition was 589 feet. This difference was found to be significant at the .01 level

The interaction of lamp color and background color is shown in Figure 5-12. Because the lamp color variable was involved in this source of variance, the data must be interpreted in light of the effect of inclusion of group 1. The exclusion of group 1 in obtaining treatment means may be seen to influence the results quantitatively but the pattern is the same in both sections of Figure 5-12. Under the clear lamp condition, there was a small superiority of the white over the black background. This effect was reversed and somewhat more pronounced for the amber lamp condition. The data can best be interpreted as indicating that contrast effects between the lamp and the vehicle are more pronounced for amber lamps than for clear ones. If amber were chosen in a DRL concept because of the Figure 5-11 data, then the data in Figure 5-12 suggest that the lamp will be more conspicuous against a dark background than against a highly reflective one.

The interaction of background and separation is illustrated in Figure 5-13. This interaction was not free of effects of group 1 because the color x background x separation interaction was used to form one-half replicates of the total matrix. Group 1 was over-represented in the single-black and dual-white conditions. This imbalance would have been corrected if group 1 had completed the second two blocks of trials. In the right-hand section of Figure 5-13, effects of contrast between lamp and background depend on whether single or dual lamps are used. With dual lamps, a black background results in a greater mean detection distance while a white background appears to be superior for a single lamp.

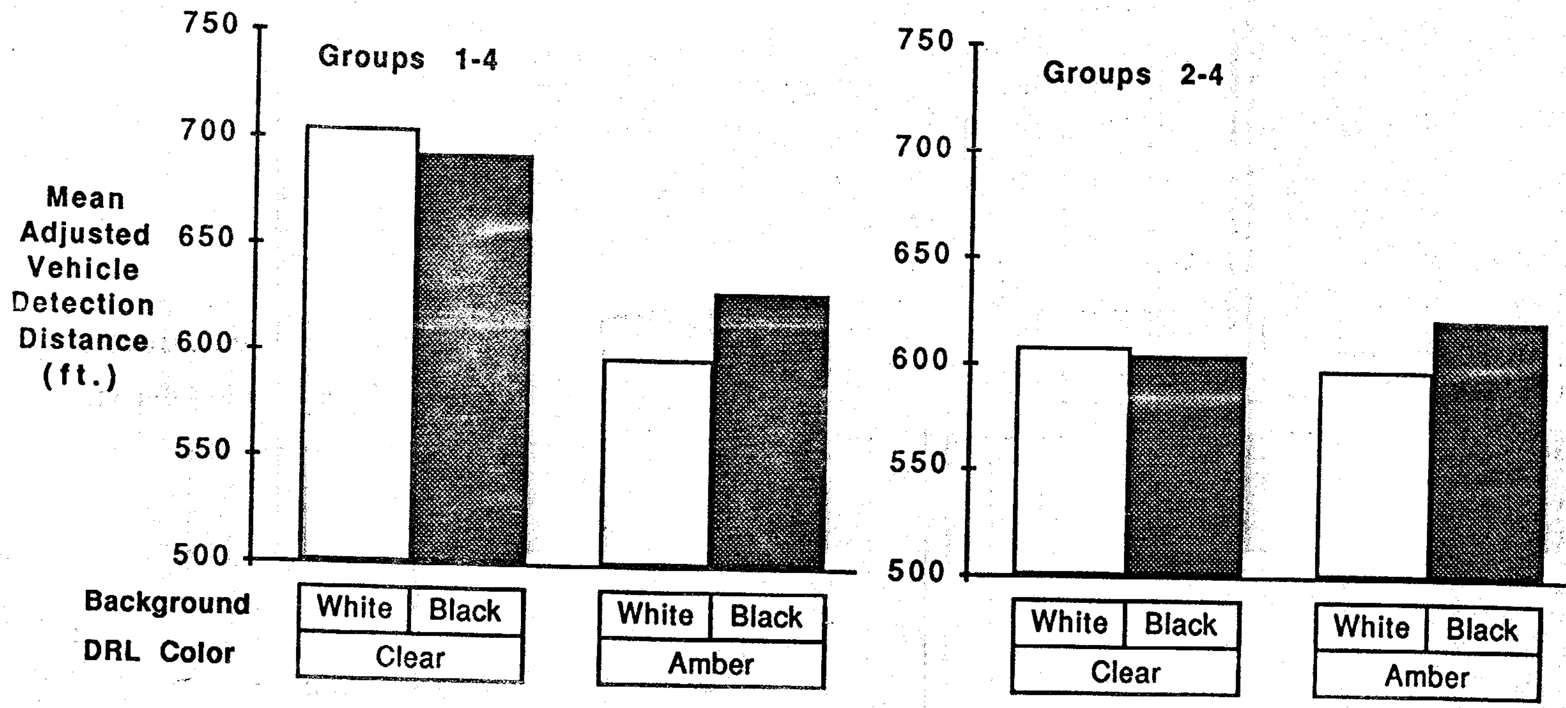

Figure 5-12. Mean Adjusted Vehicle Detection Distance as a Function of DRL Color, Background Color and Subject Groups - Analysis of Covariance Data From Non-Zero Intensity Treatments

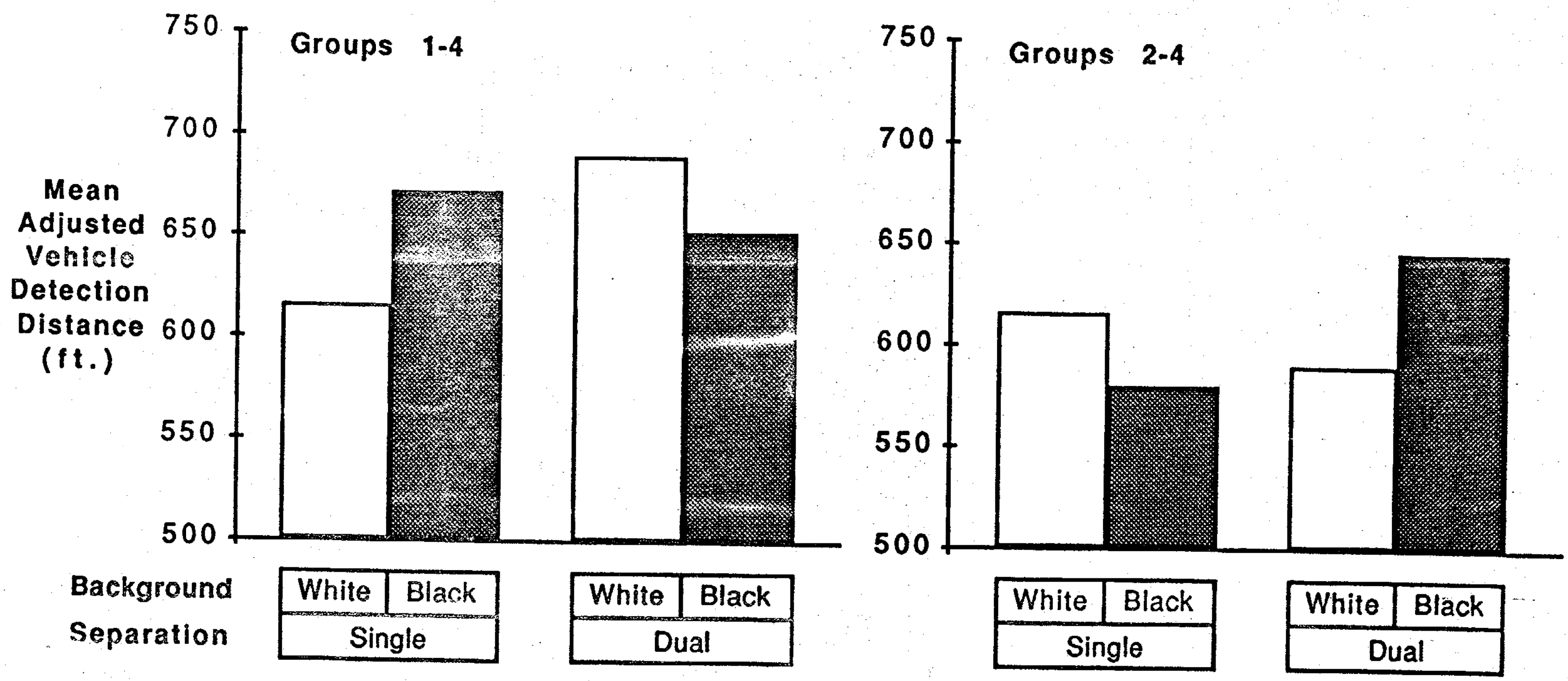

Figure 5-13. Mean Adjusted Vehicle Detection Distance as a Function of Background Color, Separation and Subject Groups - Analysis of Covariance Data from Non-Zero Intensity Treatments

6.0 TURN SIGNAL MASKING EXPERIMENT

Turn signal masking by DRL lamps mounted adjacent to the turn signals was investigated. The probability of correct turn signal detection in the presence of DRL lamps was determined as a function of the following variables:

- DRL Intensity at H-V
- DRL lamp area
- DRL lamp color - clear versus amber
- viewing distance
- ambient illumination level

6.1 Method

Lamps representing turn signals at 250 cd. were added to the DRL light bar described in Section 5.5. Turn signals were located adjacent to outboard DRL lamps and had amber lenses. Either no turn signal, the right turn signal or the left turn signal was presented in the presence of the outboard DRL lamps under daylight conditions. Subjects viewed the test vehicle from a controlled distance and reported whether there was no turn signal, a right turn signal or a left turn signal and rated the degree to which the DRL lamps were judged to interfere with the turn signal detection task.

6.2 Independent Variables

Power model #817 lamps with amber lenses were used as turn signals. These were mounted outboard of the separated DRL lamps with separation of the turn signal center point to the edge of the luminous area of the DRL lamp of 2.75 in. The intensity of the turn signals was set to 250 cd. The DRL lamps used were those described in Section 5.2. The intensity values were 500, 1000 and 2000 cd. at H-V. Lamp areas of 50, 100 and 200 sq. cm. with amber or clear lenses were used. Thus the treatment combinations employed in the turn signal masking experiment were those shown in Figure 5-1 for the dual separation condition and DRL intensities from 500 to 2000 cd. Trials were run during daylight hours from about 11 AM to 4 PM during November. Ambient illumination was measured immediately following each trial using a Spectra model FC-200 photometer with a cosine corrected illuminance receptor.

6.3 Experimental Design

Eighteen DRL treatment combinations were presented with a turn signal operating. These were composed of three levels of DRL intensity, three levels of lamp area and two levels of color - clear or amber. An additional six trials were presented in which the DRL lamps were turned on but the turn signal was not operating. The DRL treatments used in the no turn signal trials were as follows:

DRL Intensity (cd.)	Lamp Area (sq. cm.)	Lamp Color
500	50	clear
1000	50	amber
2000	100	clear
500	100	amber
1000	200	clear
2000	200	amber

Ten subjects were randomly assigned to two groups. In group 1, right or left turn signal direction was selected at random for each of the 18 treartments in which a turn signal was operated. The direction was reversed for group 2. Thus if a certain DRL treatment was presented with the right turn signal on for group 1, then the left turn signal was used for this treatment in group 2. The 24 turn signal and no turn signal trials were presented to both groups at two distances - 250 and 500 ft. The order of presentation of treatments was randomized for each distance and group.

6.4 Test Site

An unused parking lot in a business district under construction was used for data collection. Viewing distances from the subject to the test vehicle of 250 and 500 feet were used. Five subjects occupied an automobile at one end of the site, while the test car and experimenter were located at the other end facing the subject car.

6.5 Apparatus

The DRL light bar mounted on the front of the test vehicle as described in Section 5.5 was used for the turn signal masking experiment. The DRL control circuit described in Section 5.5 was retained for selection of DRL lamp combinations and intensity. Turn signals were provided using the same lamp unit as the DRLs. Turn signal intensity was maintained at 250 cd. Only 100 sq. cm. amber lenses were used for the turn signal units, while amber and white lenses were used for the DRLs. A circuit box was constructed to control the turn signals. This included a variable resistor and volt meter to maintain a DC voltage corresponding to 250 cd., and a three position toggle switch to control left-right turn indication, along with an "off" position. A standard automobile flasher unit was used to control flash rate of the turn indication. The test car battery and alternator provided electrical power for both DRLs and turn indicators.

A Spectra model FC-200 photometer with a cosine corrected illuminance probe was used to measure ambient lighting conditions at the time of each trial. Measurements were indicated in lux, with a potential range of 0 to 300,000. The photometer was located in the test vehicle with the probe on the roof so that it received direct sunlight.

Two way communications were maintained between the test vehicle and the subject vehicle by means of CB radios.

6.6 Procedures

Vision tests were administered to test subjects at the Carlow office in Merrifield, Virginia. Subjects were then transported to the test site. A standard set of instructions explaining the procedures was read and questions were answered by the experimenter. The 24 experimental trials were then administered at each distance.

6.6.1 Vision Tests

Two vision tests were applied to all subjects. Visual acuity was tested using a standard Snellen chart. Contrast sensitivity was tested using the VISTECH Consultants Incorporated VCTS 6500 test.

6.6.2 Instructions to Subjects

A standard set of instructions was read to each group of subjects after arrival at the test site. These instructions directed the subjects to observe the test vehicle when told to by the experimenter and to determine the presence or absence of a flashing turn signal. The turn signal was demonstrated to the subjects. Subjects were instructed to mark an individual data sheet with a "Right", "Left" or "None" response and to indicate the degree to which they agreed with the statement "DRL makes turn signal more difficult to see." on a five point scale. Following the written instructions, the experimenter answered any questions.

6.6.3 Trial Procedure

The experimenter positioned the subject vehicle at a predetermined position and read the instructions to subjects. One subject was told to operate the hand held transceiver in the subject vehicle during trials. The experimenter then drove the DRL test vehicle to a second location which established the viewing distance (250 or 500 ft.) and positioned it pointing at the front of the subject vehicle. The turn signals were then demonstrated to the subjects.

Treatments in the turn signal masking experiment were the 24 combinations of levels of the independent variables and turn signal direction or absence. These were identified in the run schedule by the integers 1 to 24. The experimenter consulted the run schedule to determine the next trial and treatment number and consulted a treatment table using the treatment number. This indicated levels of independent variables for each treatment and switch settings necessary to obtain these. The DRL lamp lenses were installed to obtain the correct color (amber or clear) and, if the lamp area for the next trial was 50 sq. cm., then masks were installed on the DRL lamps.

Inside the vehicle, the driver set switches on the DRL control box according to the treatment table. Next the variable resistor was adjusted with the engine above idle speed so that the correct voltage across the DRL lamps was obtained. The voltage necessary for the desired intensity was given as a function of area and color in the treatment table. The DRL lamps were then turned off. The experimenter then announced the next trial number to the subjects via radio. When the subjects were ready, the DRL lamps and the right or left turn signal (if any) were switched on for 10 seconds.

While the lamps were on, the experimenter monitored the DRL and turn signal voltages. The subjects were then instructed to mark their data sheets for the trial and, while this was being done, the experimenter read the photometer and recorded the ambient illumination level.

6.7 Subjects

Ten Carlow employees served as subjects in the turn signal masking experiment. All subjects were licensed drivers, had normal corrected or uncorrected acuity and fell within the normal range on the contrast sensitivity test. Subjects included five males and five females having the following age distribution:

Age	Number
< 25	3
25 -35	3
> 35	4

6.8 Results

The turn signal masking data consisted of 480 direction or no turn signal responses and 307 ratings of interference of the DRL lamps with the turn signal. These were subjected to multiple regression analyses and analysis of variance. The range of ambient illumination under which turn signal detection trials were run was 4900 to 100000 lux with a mean of 31135 lux.

6.8.1 Probability of Correct Detection

Subject responses, which were "right turn signal", "left turn signal" or "no turn signal", were scored and converted to a variable which was equal to 1 if correct and 0 if in error. Means of this variable are equal to the probability of correct turn signal detection. The probability of correct variable was subjected to multiple regression analysis using the following variable coding:

- DRL intensity - 500, 1000, or 2000 cd.
- lamp area - 50, 100, or 200 sq. cm.
- DRL color
  - 0 = clear
  - 1 = amber
- viewing distance - 250 or 500 ft.
- ambient illumination in lux.

The results of this analysis are shown in Table 6-1. The multiple correlation coefficient was found to be .299 with all independent variables listed above included in the model. Lamp area, viewing distance and ambient illumination were found to have significant effects on turn signal detection performance. DRL intensity was not found to exert a main effect on detection performance within the range of intensities studied here.

The 360 trials run with a turn signal operating (right or left) constituted a factorial design. Therefore, these could be subjected to analysis of covariance with the effect of ambient illumination removed statistically. The 120 trials in which no turn signal was presented were deleted from this analysis. In the 360 right/left trials, the grand probability of correct detection was .811, the grand mean ambient illumination was 32232 lux and the regression coefficient for the effect of ambient illumination was -.0000001. Therefore probability of correct turn signal detection adjusted to remove the general effect of ambient illumination was calculated as follows where P_{adj} is adjusted probability of correct detection, **P** is measured probability thereof and **X** is measured ambient illumination.

$$P_{adj} = P - [-.0000001 \times (X - 32232)] \quad \text{or:}$$

$$P_{adj} = P + .0000001\ X - .0032232$$

The analysis of covariance of the adjusted probability measure is shown in Table 6-2. In terms of main effects, the Table 6-2 data are in agreement with the previous regression analysis in that viewing distance and lamp area were found to be significant at the .001 level. These main effects are shown in Figure 6-1. Correct turn signal detection probability decreased regularly with increasing DRL area and was markedly influenced by viewing distance.

A number of interactions were found to be statistically significant at the .001 level. These were area x color , intensity x area x color and distance x intensity x area x color. The interaction of lamp area and color is illustrated in Figure 6-2. For lamp areas in the range from 50 to 100 sq. cm., amber DRL lamps appeared to produce greater masking than did clear lamps. At the 200 sq. cm. level of lamp area, however, this relationship was reversed. The 200 sq. cm. clear condition is representative of a headlamp and this treatment produced a greater degree of masking than did the other area and color combinations.

The interaction of DRL intensity, area and color is illustrated in Figure 6-3. For 50 sq. cm. DRL lamps with clear lenses, detection performance declined as a function of DRL area although the rate of decrease appeared to be less for the 1000 cd. condition than for the other intensity levels. For amber lamps, the decrease in probability with lamp area was less clear-cut. for 100 sq. cm. lamps, the 1000 cd. intensity condition appeared to produce better detection performance than did the other intensity levels. For the 200 sq. cm. lamp area condition, decrements in probability of detection were in order of increasing lamp intensity.

Table 6-1. Multiple Regression Analysis of Probability of Correct Turn Signal Detection

Multiple Regression of Turn Signal Detection Probability
N = 480
R = .299

Independent Variable	Raw Score Coefficient	Standardized Coefficient	T Statistic	Alpha Level
Constant	1.258	0.000	18.853	<0.001
Intensity	-0.000	-0.064	-1.452	0.147
Area	-0.001	-0.125	-2.827	0.005
Color	-0.031	-0.044	-0.995	0.320
Distance	-0.001	-0.321	-6.033	<0.001
Ambient	0.000	0.206	3.831	<0.001

Analysis of Variance

Source	Sum of Squares	Degrees of Freedom	F-Ratio	Alpha Level
Regression	5.406	5	9.302	<0.001
Residual	55.092	474	—	—

Table 6-2. **Analysis of Covariance of Adjusted Probability of Correct Turn Signal Detection From Right and Left Turn Signal Conditions**

Source	df	SS	MS	F	Alpha
Distance (D)	1	3.48	3.480	31.950	0.001
DRL Intensity (I)	2	0.42	0.210	1.928	0.250
Lamp Area (A)	2	1.15	0.575	5.279	0.001
Lamp Color (C)	1	0.29	0.290	2.662	0.250
Subjects	9	7.82	0.869	7.977	———
D x I	2	0.6	0.300	2.754	0.100
D x A	2	0.46	0.230	2.112	0.250
D x C	1	0.08	0.080	0.734	———
I x A	4	0.47	0.118	1.079	>0.250
I x C	2	0.15	0.075	0.689	———
A x C	2	1.14	0.570	5.233	0.001
D x I x A	4	0.14	0.035	0.321	———
D x I x C	2	0.48	0.240	2.203	0.250
D x A x C	2	0.63	0.315	2.892	0.100
I x A x C	4	1.72	0.430	3.948	0.001
D x I x A x C	4	1.82	0.455	4.177	0.001
Residual (Error)	315	34.31	0.109	———	———
Total	359	55.16	———	———	———

The interaction of distance, DRL intensity, area and color is illustrated in Figures 6-4 and 6-5. The data for the 250 foot distance are shown in Figure 6-4. For clear lamps, performance decrements due to lamp area were found as a function of lamp intensity. For amber lamps, the decrement in performance associated with lamp area was noted only for the 2000 cd. intensity condition. The data for the 500 foot viewing distance are shown in Figure 6-5. A general trend toward greater decrements in detection probability with increasing lamp area appeared in the clear lamp data at 500 feet. For clear lamps at 500 feet, the decrement was greater for intensities of 500 and 2000 cd. than for the 1000 cd. level. Amber lamps at 500 feet showed little evidence of a general effect of lamp area. The primary differences occurred for the 100 sq. cm. lamp area with the 1000 cd. intensity level producing better performance than the other two levels.

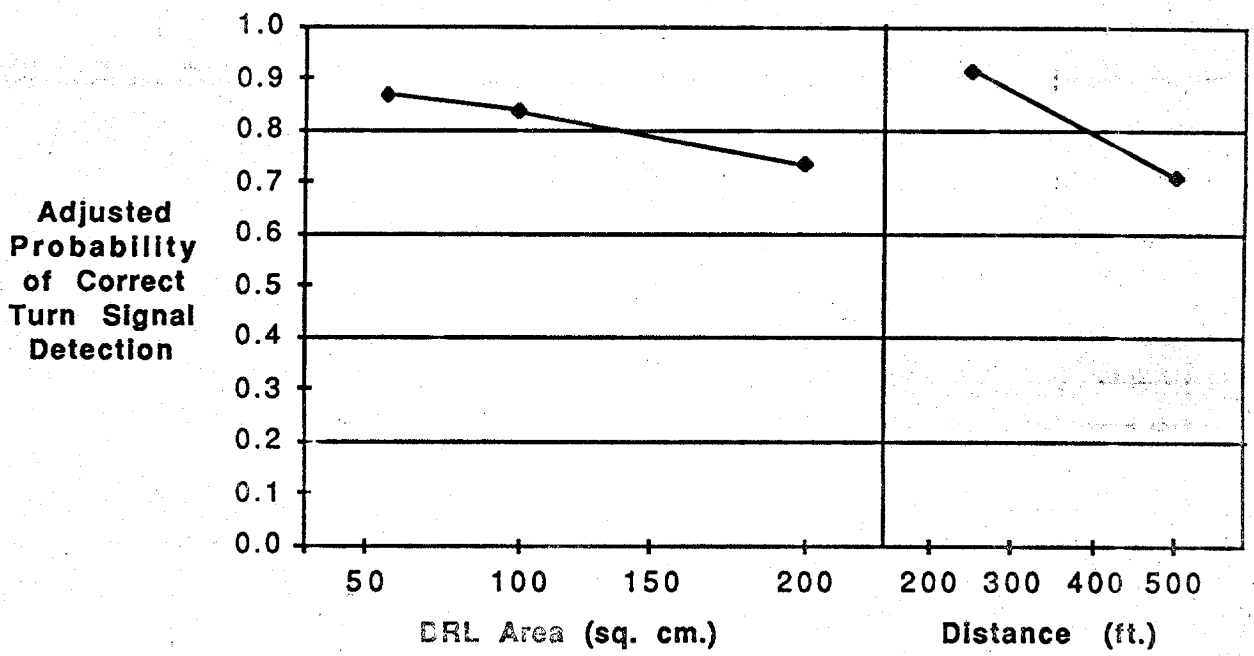

Figure 6-1. Adjusted Probability of Correct Turn Signal Detection as a Function of DRL Area and Distance - Analysis of Covariance Data From Right and Left Turn Signal Conditions

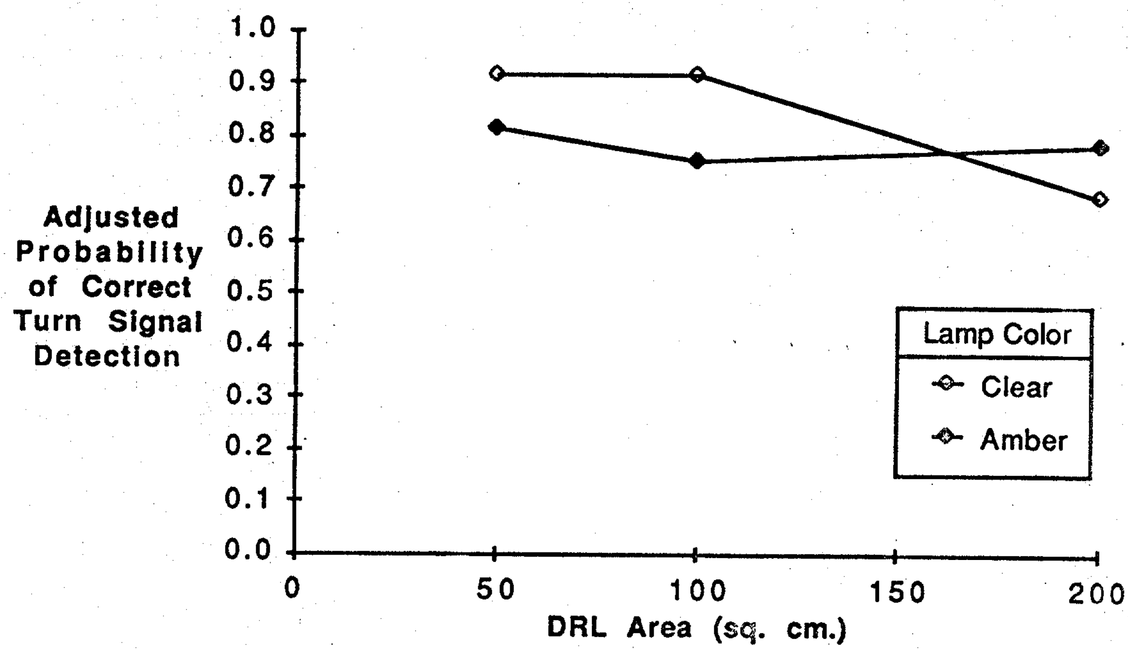

Figure 6-2. **Adjusted Probability of Correct Turn Signal Detection as a Function of DRL Area and Color - Analysis of Covariance Data From Right and Left Turn Signal Conditions**

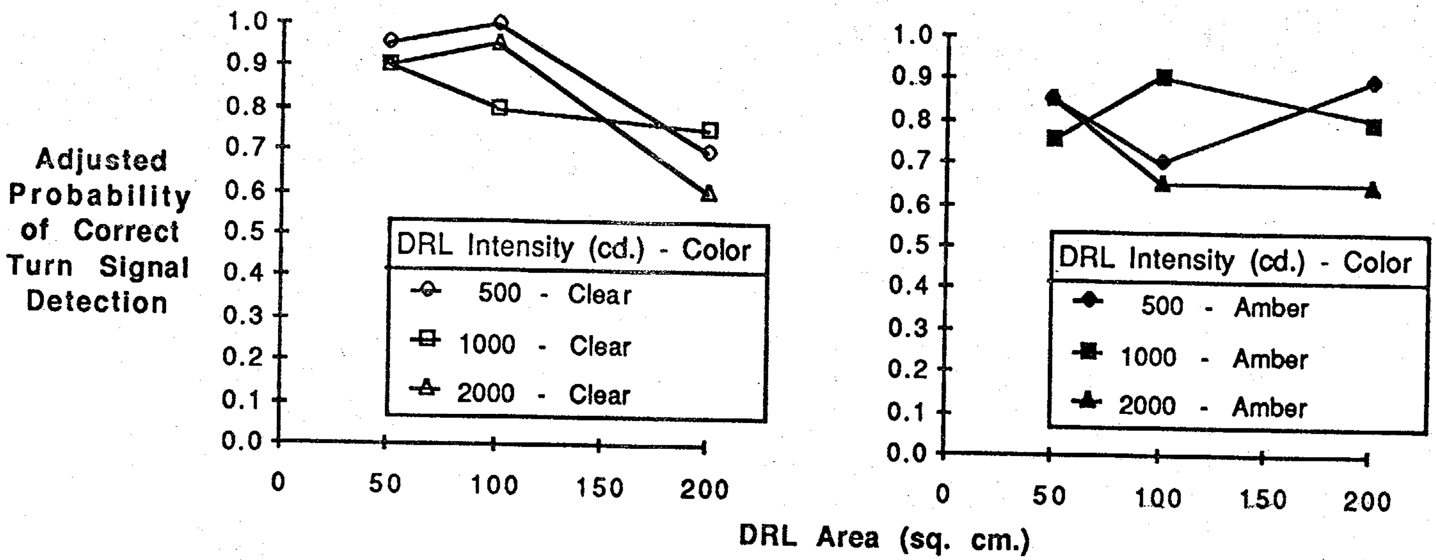

Figure 6-3. Adjusted Probability of Correct Turn Signal Detection as a Function of DRL Intensity, Area and Color - Analysis of Covariance Data From Right and Left Turn Signal Conditions

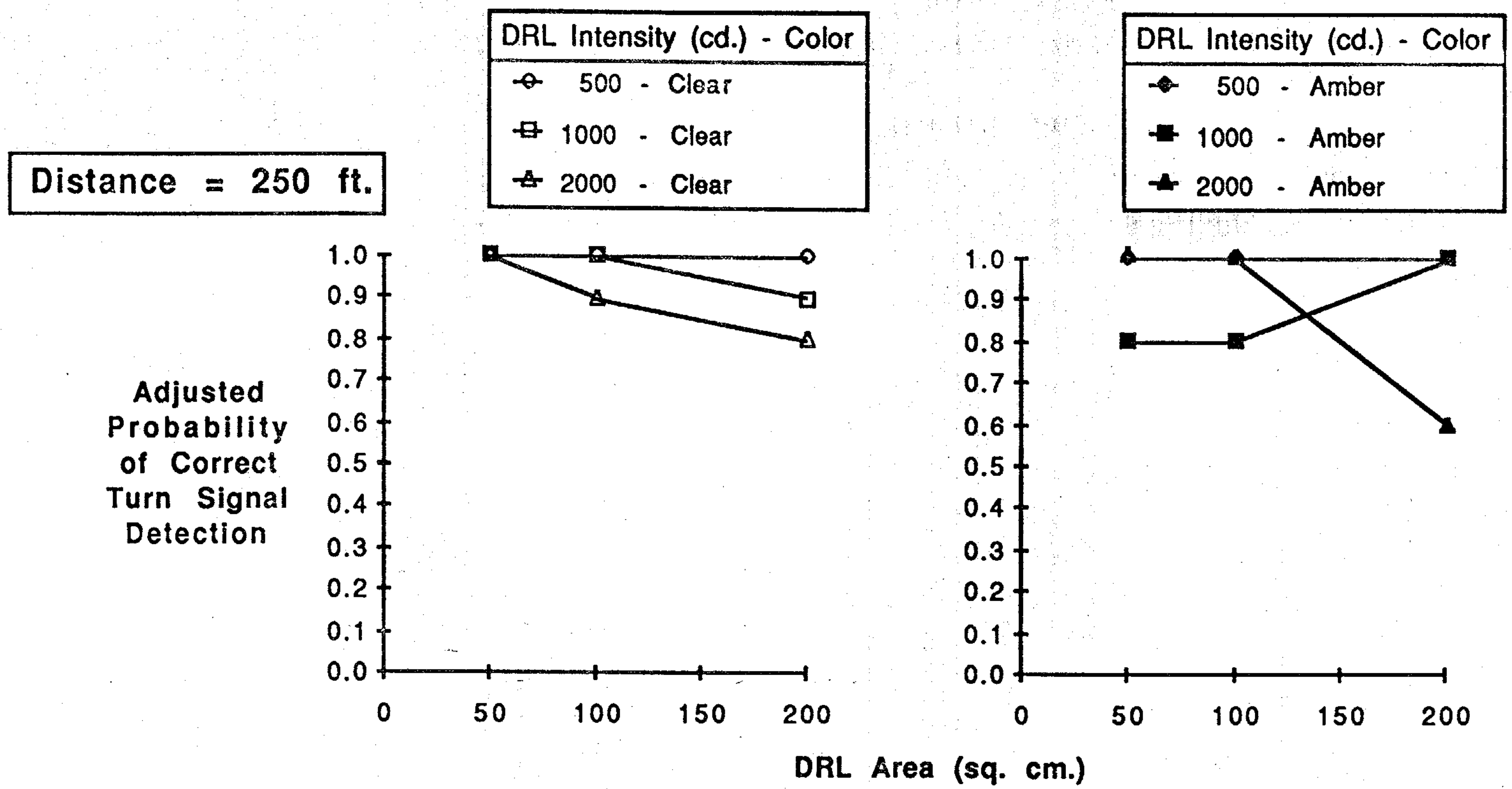

Figure 6-4. Adjusted Probability of Correct Turn Signal Detection as a Function of DRL Intensity, Area and Color at Distance = 250 ft. - Analysis of Covariance Data From Right and Left Turn Signal Conditions

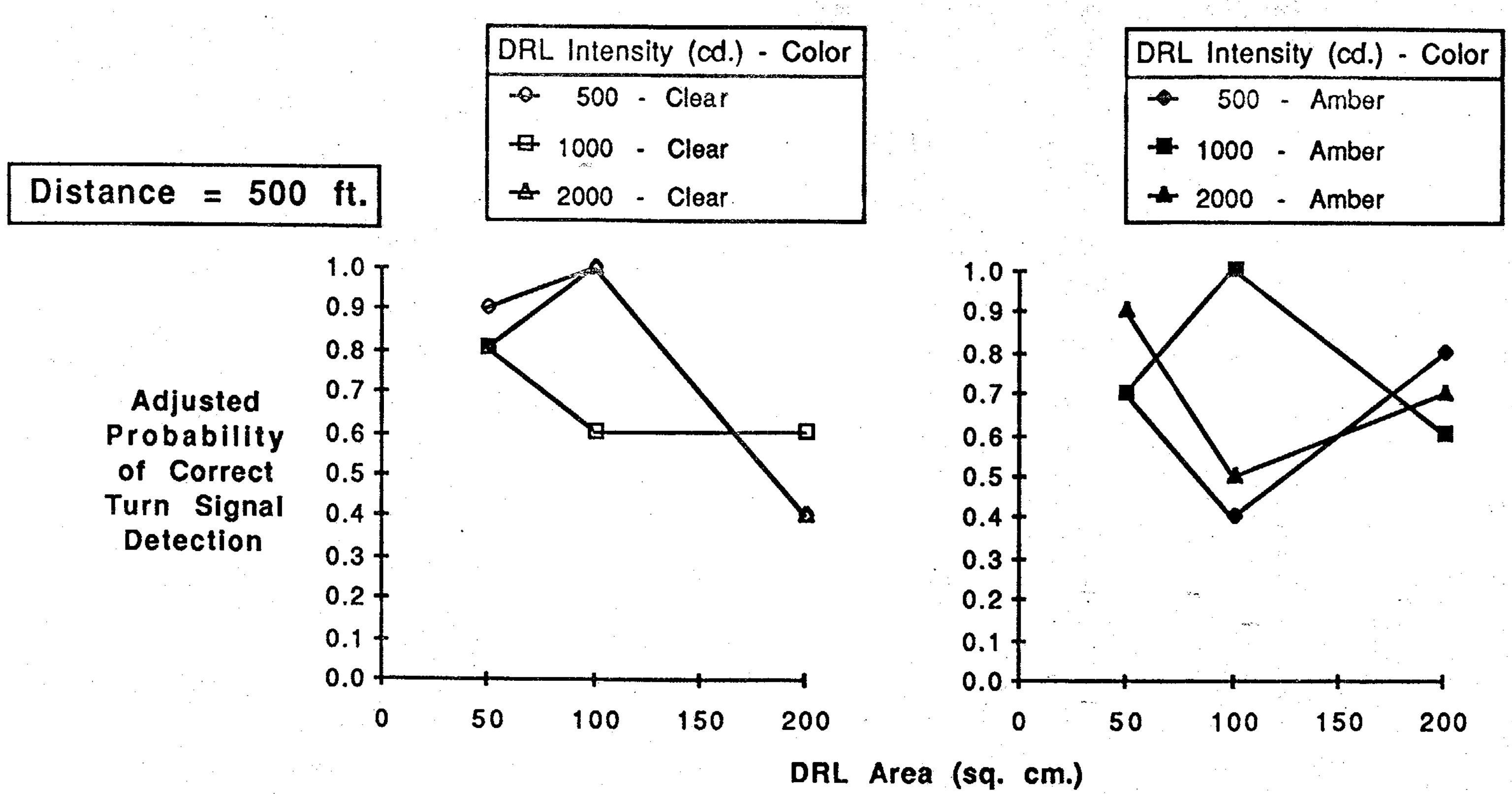

Figure 6-5. Adjusted Probability of Correct Turn Signal Detection as a Function of DRL Intensity, Area and Color at Distance = 500 ft. - Analysis of Covariance Data From Right and Left Turn Signal Conditions

6.8.2 Rating of Turn Signal Detection Difficulty

The 480 trials in the turn signal detection experiment yielded 307 rating responses because subjects did not rate trials in which they judged that no turn signal was present. The difficulty rating data were subjected to the same regression analysis as was probability of correct detection. The results are shown in Table 6-3. The multiple correlation between rating and the independent variables was found to be .555. All independent variables except distance had significant effects on rating. Howevcer, the rating results showed conspicuous lack of agreement with the detection performance results. Lamp color had a significant effect on ratings with amber judged to produce greater difficulty than clear. However, the detection probability data did not support this. Viewing distance which was the major determinant of detection performance did not produce a significant rating effect.

The effects on mean rating of DRL intensity and lamp area which were both significant are shown in Figure 6-6. The mean rating of difficulty increased with both lamp area and DRL intensity. The lamp area effect on detection probability was also found to be significant but that of intensity was not. In view of the general disagreement between rating and detection probability results, further analysis of the rating data was not pursued. The probability of correct detection data represent performance while the ratings are subjective. The situation is somewhat similar to that reported by Rumar (1980) in which amber lamps were judged by observers to have greater conspicuity value than clear lamps but this effect was not supported by the detection performance data. Since the rating data were found to be in considerable disagreement with the detection performance data, it was concluded that, for the case of turn signal masking, rating response data did not produce a valid criterion. The probability of correct detection data provide the preferred method for evaluation of masking effects.

Table 6-3. Multiple Regression Analysis of Turn Signal Detection Difficulty Ratings

Multiple Regression of Turn Signal Detection Difficulty Ratings
N = 307
R = .555

Independent Variable	Raw Score Coefficient	Standardized Coefficient	T Statistic	Alpha Level
Constant	1.563	0.000	5.585	<0.001
Intensity	0.001	0.331	6.767	<0.001
Area	0.004	0.164	3.389	0.001
Color	0.645	0.243	5.056	<0.001
Distance	0.001	0.083	1.360	0.175
Ambient	0.000	0.238	3.862	<0.001

Analysis of Variance

Source	Sum of Squares	Degrees of Freedom	F-Ratio	Alpha Level
Regression	166.459	5	26.786	<0.001
Residual	374.102	301	———	———

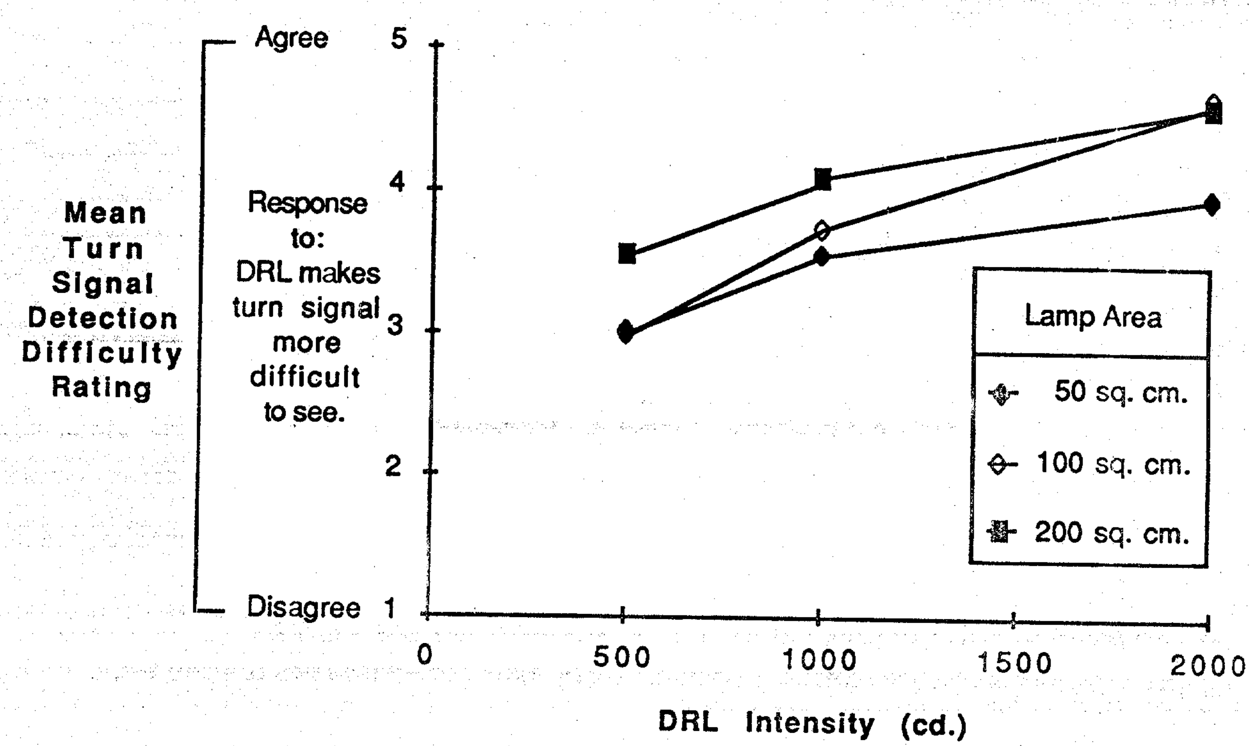

Figure 6-6. **Mean Rating of Turn Signal Detection Difficulty as a Function of DRL Intensity and Lamp Area**

7.0 REARVIEW MIRROR GLARE

Glare produced at a vehicle rearview mirror by DRL lamps mounted behind the vehicle was investigated. Ratings of discomfort glare were used as one criterion and subjects were asked to indicate whether they would or would not flip the mirror to the reduced intensity position (dim the mirror) if they were driving the vehicle. The independent variables in the rearview mirror glare experiment were as follows:

- DRL Intensity at H-V
- DRL lamp area
- DRL lamp color - clear versus amber
- DRL separation - dual separated versus single center-mounted
- ambient illumination level.

7.1 Method

Rearview mirror glare produced under dawn/dusk illumination conditions by a following vehicle was considered to represent a worst glare case because the distance involved could be a few tens of feet and the lamps would be seen at a central horizontal angle. The rearview mirror experiment was performed during the period from one half hour before sunset to one half hour after sunset during November. Subjects were seated in the driver's seat of the DRL test vehicle which was located in a parking lot and the DRL lamps were mounted on a tripod located 20 feet behind the rear of the vehicle. Subjects observed the rearview mirror and rated the level of discomfort glare on the DeBoer scale (Perel, Olson, Sivak and Medlin,1984) which is a nine point scale of discomfort glare which runs from 1 (unbearable) to 9 (just noticeable). Subjects were also asked if they would flip the mirror to the reduced intensity position if they experienced the level of glare while driving.

7.2 Independent Variables

The DRL lamps used were those described in Section 5.2. The intensity values were 500, 1000 and 2000 cd. at H-V. Single center mounted and dual separated lamps with areas of 50, 100 and 200 sq. cm. and amber or clear lenses were used. Thus the treatment combinations employed in the rearview mirror glare experiment were those shown in Figure 5-1 for DRL intensities from 500 to 2000 cd. Trials were run during the period from one half hour before sunset to one half hour after sunset. Ambient illumination was measured immediately following each trial using a Spectra model FC-200 photometer with cosine corrected receptor.

7.3 Experimental Design

Thirty-six treatment combinations were presented. These were composed of three levels of DRL intensity, three levels of lamp area, two levels of color - clear or amber and two levels of separation - single or dual. The clear and amber conditions were blocked with eighteen trials being presented under each condition. The assignment of clear or amber to the first or second block was counterbalanced over subjects. Within a block, treatments involving areas of 100 or 200 sq. cm. were randomly assigned to trials. The 50 sq. cm. treatments were grouped and the order of presentation was randomized separately. The 50 sq. cm. group was then inserted at a randomly selected point in the general trial schedule. This randomization was done separately for each of the ten subjects.

7.4 Test Site

The test vehicle used during the vehicle detection and turn signal masking experiments was also used during the rearview mirror glare experiment. The DRL lamps were mounted on a tripod 20 feet behind the rear of the car. The vehicle was parked in a parking lot for data collection. Subjects were seated in the driver's position and the experimenter sat in the front passenger seat, controlling DRL configuration and directing the subject to respond to each.

7.5 Apparatus

The DRL light bar described in Section 5.5 was used for the rearview mirror glare experiment. This was mounted on a tripod located 20 ft. behind the test vehicle and was powered from the vehicle using extension cables. The lamp center point was mounted at a height of four feet which was the height of the rearview mirror and approximated a typical eye height for a person seated in the vehicle. The DRL control circuit described in Section 5.5 was retained for selection of DRL lamp combinations and intensity. The test car battery and alternator provided electrical power for the DRL lamps. A Spectra model FC-200 photometer with a cosine corrected illuminance probe was used to measure ambient lighting conditions at the time of each trial. Measurements were indicated in lux, with a potential range of 0 to 300,000. The photometer was located in the test vehicle with the probe on the roof.

7.6 Procedures

Vision tests were administered to test subjects at the Carlow office in Merrifield, Virginia. A standard set of instructions explaining the procedures was read and questions were answered by the experimenter. The 36 experimental trials were then administered.

7.6.1 Vision Tests

Two vision tests were applied to all subjects. Visual acuity was tested using a standard Snellen chart. Contrast sensitivity was tested using the VISTECH Consultants Incorporated VCTS 6500 test.

7.6.2 Instructions to Subjects

A standard set of instructions was read to each subject. These instructions directed the subjects to observe the rearview mirror when told to by the experimenter and to judge the degree of glare produced. The DeBoer scale for glare judgments was posted in the test vehicle and could be referred to by subjects as necessary.

7.6.3 Trial Procedure

Treatments in the rearview mirror glare experiment were the 36 combinations of levels of the independent variables. These were identified in the run schedule by the integers 1 to 36. The experimenter consulted the run schedule to determine the next trial and treatment number and consulted a treatment table using the treatment number. This indicated levels of independent variables for each treatment and the switch settings necessary to obtain these. The DRL lamp lenses were installed to obtain the correct color (amber or clear) and, if the lamp area for the next trial was 50 sq. cm., then masks were installed on the DRL lamps.

Inside the vehicle, the experimenter set switches on the DRL control box according to the treatment table. Next the variable resistor was adjusted with the engine above idle speed so that the correct voltage across the DRL lamps was obtained. The voltage necessary for the desired intensity was given as a function of area and color in the treatment table. While the lamps were on, the experimenter monitored the DRL voltage. The subject was then asked for his/her rating and mirror response. The experimenter recorded these and then read the photometer and recorded the ambient illumination level.

7.7 Subjects

Ten Carlow employees served as subjects in the rearview mirror glare experiment. All subjects were licensed drivers, had normal corrected or uncorrected acuity and fell within the normal range on the contrast sensitivity test. Subjects included six males and four females having the following age distribution:

Age	Number
< 25	2
25 -35	3
> 35	5

7.8 Results

The rearview mirror glare data consisted of 360 DeBoer scale ratings and mirror dimming responses. These were subjected to multiple regression analysis and analysis of variance. The range of ambient illumination under which rearview mirror glare trials were run was 1 to 7000 lux with a mean of 685 lux.

7.8.1 Discomfort Glare Rating

The discomfort glare ratings ranged from 1 to 9. These were subjected to multiple regression analysis using the following variable coding:

- DRL intensity - 500, 1000 or 2000 cd.
- lamp area - 50, 100 or 200 sq. cm.
- lamp color
  - 0 = clear
  - 1 = amber
- DRL separation
  - 0 = single center mounted
  - 1 = dual separated
- ambient illumination in lux.

The results of this analysis are shown in Table 7-1. None of the independent variables was found to exert a significant influence on rating and the total F-ratio test for the regression reached only the 0.387 level of significance.

Since the regression analysis of the rating data did not show a significant effect of ambient illumination, an analysis of variance was conducted using the rating data directly without an adjustment for ambient illumination. The results of this analysis are shown in Table 7-2. The assumptions were the same as those for the detection distance analysis. The interactions with subjects were pooled to form the error term. The main effect of DRL intensity was found to be significant at the 0.001 level and the main effects of DRL area and separation were found to reach the 0.05 level. The analysis of variance had somewhat greater power than did the regression analysis due to the removal of the subject main effect from the error term.

The main effects of DRL intensity, DRL area and separation are shown in Figure 7-1. Variation in the mean rating as a function of DRL intensity was found to be considerable - the mean rating varying from the "satisfactory" range for 500 cd. to the "disturbing" range for 2000 cd. Smaller quantitative effects of DRL area and separation were found. The 200 sq. cm. condition appeared to result in slightly greater glare than did the 50 and 100 sq. cm. conditions. Similarly, dual lamps were rated as producing slightly greater glare than a single DRL lamp. This effect was presumably due to the greater total intensity at the mirror resulting from the dual DRL condition.

The DeBoer glare rating scheme was treated as a numerical scale yielding at least interval data in performing regression analysis and analysis of variance. Since it is difficult to be sure that such rating data constitute a true interval scale, this approach may not be entirely appropriate. Therefore frequency distributions were obtained for the possible responses on the DeBoer scale (the integers from 1 to 9) for each level of DRL intensity. These distributions are shown in Figure 7-2.

Table 7-1. Multiple Regression Analysis of Discomfort Glare Rating

Multiple Regression of Discomfort Glare Rating
N = 360
R = .121

Independent Variable	Raw Score Coefficient	Standardized Coefficient	T Statistic	Alpha Level
Constant	-8.583	0.000	-0.189	0.850
Intensity	-0.025	-0.060	-1.139	0.255
Area	0.287	0.068	1.286	0.199
Color	27.034	0.051	0.973	0.331
Separation	27.483	0.052	0.991	0.323
Ambient	-0.005	-0.024	-0.444	0.657

Analysis of Variance

Source	Sum of Squares	Degrees of Freedom	F-Ratio	Alpha Level
Regression	364430.711	5	1.052	0.387
Residual	.245187 E+08	354	_____	_____

Table 7-2. **Analysis of Variance of Discomfort Glare Rating**

Source	df	SS	MS	F	Alpha
DRL Intensity (I)	2	589.210	294.605	137.135	0.001
Lamp Area (A)	2	13.350	6.675	3.107	0.050
Lamp Color (C)	1	0.010	0.010	0.005	——
Separation (D)	1	10.000	10.000	4.655	0.050
Subjects	9	113.890	12.654	5.890	——
I x A	4	9.120	2.280	1.061	>0.250
I x C	2	4.220	2.110	0.982	——
I x D	2	5.220	2.610	1.215	>0.250
A x C	2	4.970	2.485	1.157	>0.250
A x D	2	0.890	0.445	0.207	——
C x D	1	0.400	0.400	0.186	——
I x A x C	4	4.910	1.228	0.571	——
I x A x D	4	2.800	0.700	0.326	——
I x C x D	2	8.510	4.255	1.981	0.250
A x C x D	2	0.010	0.005	0.002	——
I x A x C x D	4	0.570	0.143	0.066	——
Residual (Error)	315	676.710	2.148	——	——
Total	359	1444.790	——	——	——

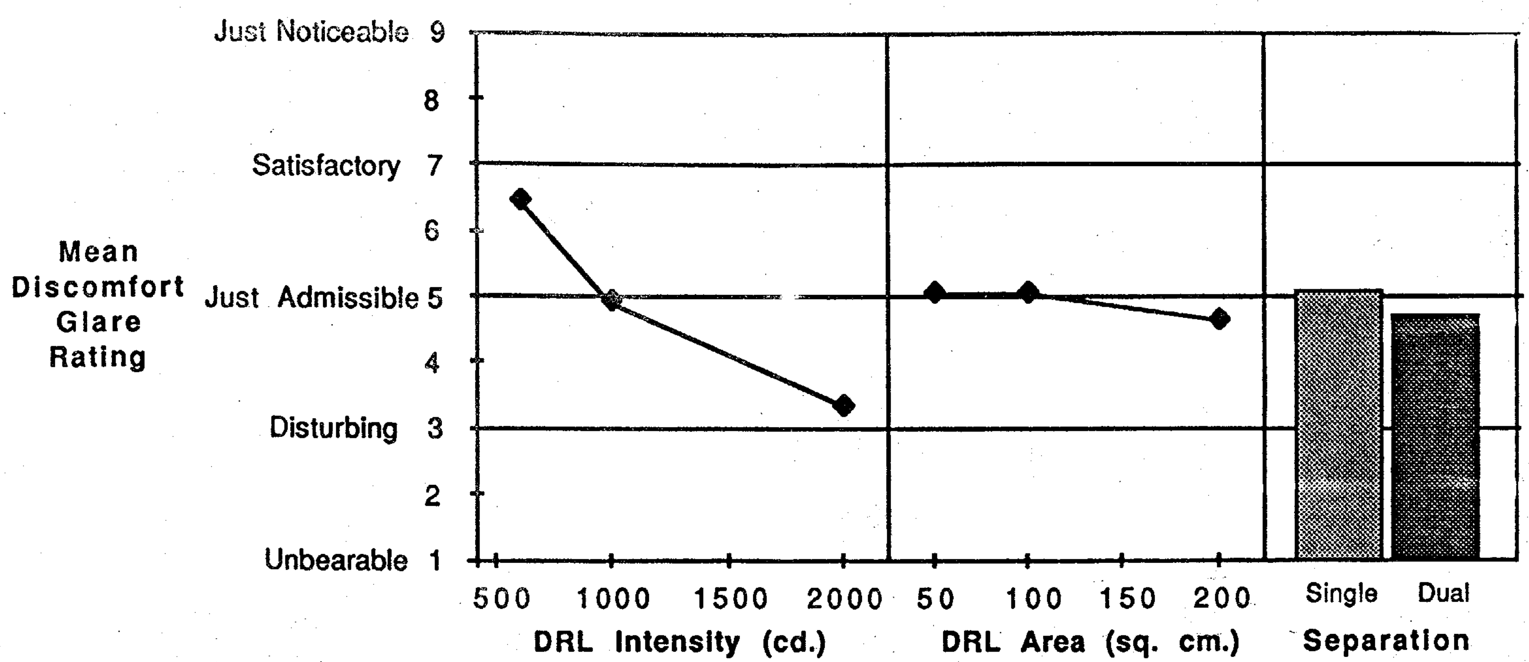

Figure 7-1. Mean Discomfort Glare Rating as a Function of DRL Intensity, DRL Area and Separation

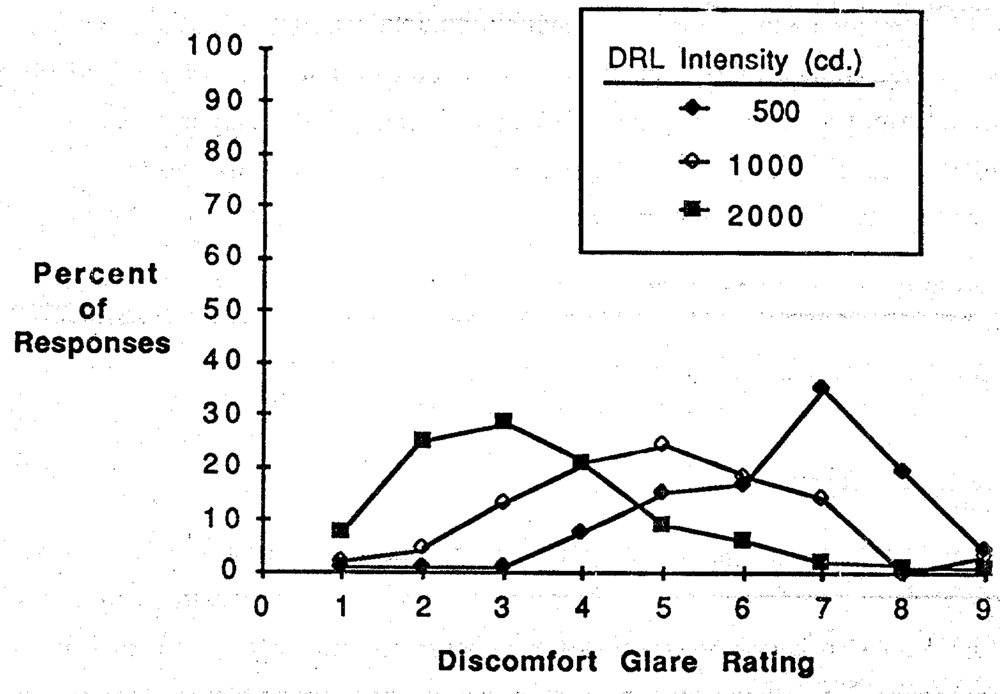

Figure 7-2. **Distribution of Discomfort Glare Rating as a Function of DRL Intensity**

The modal response to the three levels of DRL intensity were as follows:

- 500 cd. - 7 (satisfactory)
- 1000 cd. - 5 (just admissible)
- 2000 cd. - 3 (disturbing)

The rating data suggest that, for the case involving minimum distance of a following vehicle studied here, a DRL intensity of 500 cd. seen by the driver via the rearview mirror does not present a serious glare problem while the 2000 cd. level certainly does. The 1000 cd. level appears to represent a marginal degree of discomfort glare.

7.8.2 Probability of Mirror Dimming Response

The mirror dimming response was "yes" or "no" to the question "Would you dim the mirror if you were driving?". This was coded for analysis as 0 = no and 1 = yes. A mean of this variable is, therefore, the probability of a mirror dimming response. The mirror dimming response variable was subjected to the same regression analysis as was the discomfort glare rating. The results are shown in Table 7-3. DRL intensity was found to be significant beyond the 0.001 level and the effect of ambient illumination exceeded the 0.05 level. The analysis of variance for the total regression relationship was found to be significant at the .001 level. Since the effect of ambient illumination on the probability of rearview mirror dimming response was found to be significant, an analysis of covariance was carried out in which the data were adjusted for the effect of ambient illumination as was done in the case of vehicle detection distance. The grand probability of rearview mirror dimming in the data sample was .439, the grand mean ambient illumination was 685 lux and the regression coefficient for the effect of ambient illumination was .0000377. Therefore, probability of rearview mirror dimming response adjusted to remove the general effect of ambient illumination was calculated as follows where P_{adj} is adjusted probability of dimming response, **P** is measured probability thereof and **X** is measured ambient illumination:

$$P_{adj} = P - [.0000377 \times (X - 685)] \quad \text{or:}$$

$$P_{adj} = P - .0000377\,X + .0258$$

The analysis of covariance of the adjusted probability measure is shown in Table 7-4. The results of this analysis are in agreement with the previous regression analysis in that the DRL intensity effect was the only one which reached statistical significance. The effect of DRL intensity is illustrated in Figure 7-3. Mirror dimming response probability adjusted for effects of ambient illumination was found to increase regu[illegible] a function of DRL intensity in the range from 500 to 2000 cd.

Table 7-3. Multiple Regression Analysis of Probability of Rearview Mirror Dimming Response

Multiple Regression of Probability of Rearview Mirror Dimming Response
N = 360
R = .543

Independent Variable	Raw Score Coefficient	Standardized Coefficient	T Statistic	Alpha Level
Constant	-0.128	0.000	-1.765	0.078
Intensity	<0.001	0.528	11.827	<0.001
Area	0.001	0.064	1.483	0.151
Color	-0.052	-0.053	-1.182	0.238
Separation	0.030	0.030	0.682	0.496
Ambient	<0.001	0.098	2.184	0.030

Analysis of Variance

Source	Sum of Squares	Degrees of Freedom	F-Ratio	Alpha Level
Regression	26.104	5	29.546	<0.001
Residual	62.552	354	———	———

Table 7-4. **Analysis of Covariance of Adjusted Probability of Rearview Mirror Dimming Response**

Source	df	SS	MS	F	Alpha
DRL Intensity (I)	2	24.950	12.475	80.807	0.001
Lamp Area (A)	2	0.280	0.140	0.907	——
Lamp Color (C)	1	0.350	0.350	2.267	0.250
Separation (D)	1	0.050	0.050	0.324	——
Subjects	9	10.600	1.178	7.629	——
I x A	4	0.600	0.150	0.972	——
I x C	2	0.020	0.010	0.065	——
I x D	2	0.170	0.085	0.551	——
A x C	2	0.010	0.005	0.032	——
A x D	2	0.120	0.060	0.389	——
C x D	1	0.000	0.000	0.000	——
I x A x C	4	0.730	0.183	1.182	>0.250
I x A x D	4	0.330	0.083	0.534	——
I x C x D	2	0.440	0.220	1.425	0.250
A x C x D	2	0.060	0.030	0.194	——
I x A x C x D	4	0.600	0.150	0.972	——
Residual (Error)	315	48.630	0.154	——	——
Total	359	87.940	——	——	——

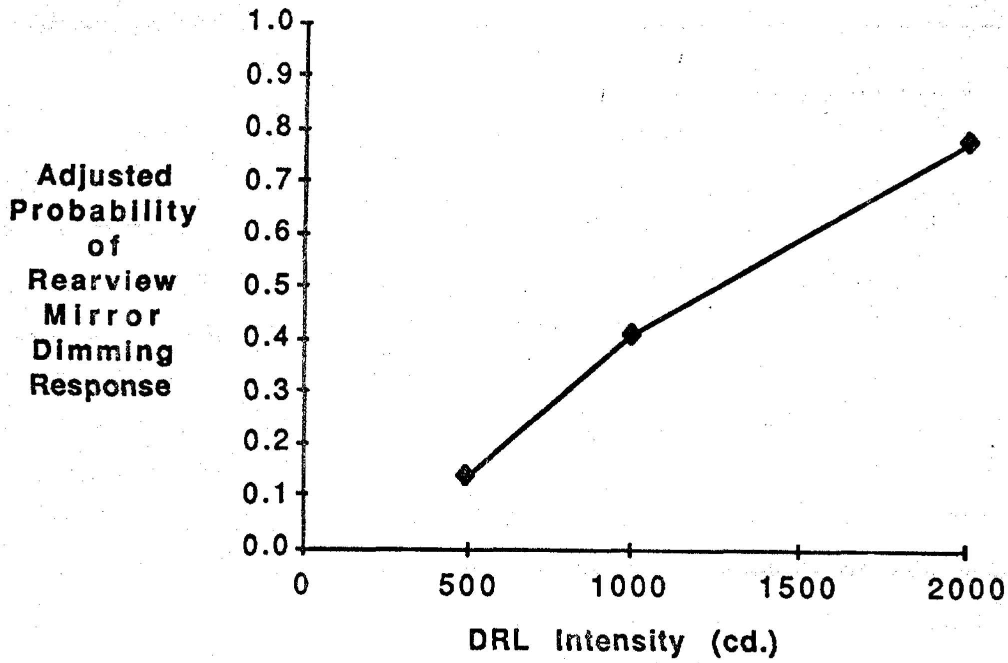

Figure 7-3. **Adjusted Probability of Rearview Mirror Dimming Response as a Function of DRL Intensity**

8.0 CONCLUSIONS AND RECOMMENDATIONS

DRL intensity has emerged as the primary determinant of DRL conspicuity in the studies conducted here. The intensity at H-V interacts with ambient illumination as was suggested by Horberg and Rumar (1979). DRL intensities below 500 cd. appear to produce detection distance improvements at lower ambient illumination (14000 to 41912 lux in the current study). At higher ambient levels (41912 to 94000 lux), however, these lower intensities appear to produce little improvement. The other DRL design parameters investigated were found to have less impact on observer performance.

8.1 DRL Intensity and Beam Pattern

The vehicle detection results suggest that depending on ambient illumination level, DRL center intensities below 500 cd. may not produce much detection distance improvement. Across ambient illumination levels, improvement in vehicle detection distance was found to result from the higher DRL intensity levels of 1000 and 2000 cd. Improvement in detection distance for the 250 to 500 cd. intensity levels was largely confined to lower ambient illumination conditions as was suggested by Horberg and Rumar (1979). The data from the current vehicle detection experiment are compared with the Horberg and Rumar (1979) data in Figure 8-1. The solid data points in Figure 8-1 represent the 30 degree peripheral angle detection data from Figure 2 in Horberg and Rumar (1979). The unfilled data points were taken from Figure 5-9 for all data across levels of ambient illumination. The range of ambient illumination was from 3000 to 6000 lux for the Horberg and Rumar data and from 14000 to 94000 lux with a mean of 41912 lux in the current vehicle detection experiment. The Horberg and Rumar data showed an increase in detection data between the 400 cd. condition and the lower intensities while this increase was not found in the current data. It appears that the difference in ambient illumination is responsible because the Figure 8-1 data have some features in common with the ambient light comparisons in Figure 5-10. In both cases, there is a range of low DRL intensities which produce no apparent increment in detection distance and then a notable improvement at some intermediate level. The characteristic intensity at which improvement is first noted appears to depend on the ambient illumination level. For the Horberg and Rumar data, no improvement was noted for DRL intensities in the 50 to 150 cd. range. Under their fairly low illumination levels, improvement was noted for the 400 cd. condition. Under the higher illumination typical of the current vehicle detection experiment, this "threshold" point occurred above 500 cd. Assuming that the ambient illumination observed during the vehicle detection experiment is characteristic of the U.S. (or, at least, is more representative than the levels observed by Horberg and Rumar) then the evidence seems to favor a DRL intensity in the 1000 to 2000 cd. range under ambient illumination conditions typical in the U.S.

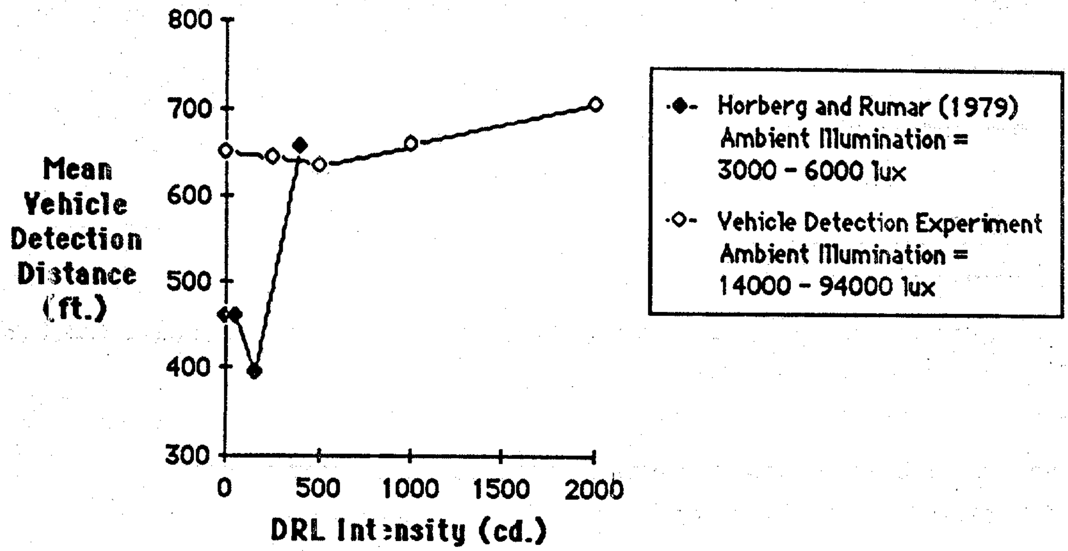

Figure 8-1. Comparison of Results of Horberg and Rumar (1979) with Results of Vehicle Detection Experiment

If the central intensity of DRL in the U.S. should be on the order of 2000 cd. for improved daytime vehicle detection distance, the question remains of an acceptable distribution at horizontal and vertical angles around the center. An approach to determining a recommended DRL beam pattern was presented by Kirkpatrick, Heasly and Bathurst (1984). These authors developed a model of vehicle conflict in which a DRL equipped vehicle was conceived of as moving along a main roadway and having the right-of-way. A second vehicle was assumed to be approaching the main roadway at low speed at a right angle intersection having traffic control (such as a stop sign). Presumably, the first driver who has the right-of-way would not greatly alter speed or heading because of detection of the second vehicle. The second driver, however, would be faced with a choice of whether to enter the intersection so that timely detection of the first vehicle will be critical. In this scenario, the likelihood of a crash given that the second driver fails to detect the DRL equipped vehicle will depend on the initial positions and velocities of the two vehicles. These were partially parameterized using a horizontal angle between the centerline of the DRL vehicle and the line of sight from the DRL vehicle to the approaching second vehicle.

The model calculated a figure of merit for a range of the above horizontal angle. This depended on whether a vehicle seen at the given angle would generate a crash if its driver did not react and on the square of the distance to an approaching vehicle seen at this angle. The model was run using three scenarios - vehicle crossing from left, vehicle approaching in opposite direction and vehicle crossing from right. The model was run over plausible ranges of initial positions, initial speeds and roadway/intersection dimensions. Figures of merit for line of sight angles to the approaching vehicle were calculated for each of the three scenarios and were then combined using equal weighting. The results of this analysis are presented in Figure 8-2.

The angle shown on the X axis in Figure 8-2 is seen from the DRL equipped vehicle. Negative angles are to the left as the DRL vehicle driver would see them and positive angles are to the right. The figure of merit was normalized relative to the maximum value obtained which was at -10 degrees. The large spike centered at -10 degrees is the result of the crossing from left and oncoming scenarios. The secondary spike centered at about 15 degrees is due to the crossing from right scenario. To the extent that the assumptions made by Kirkpatrick et. al. (1984) are representative of vehicle conflicts, the figure of merit in Figure 8-2 should approximate the relative benefit of DRL intensity emitted in the direction given by the angles shown. On this notion, it seems reasonable to assert that the DRL horizontal beam pattern should show an intensity which is proportional to the figure of merit at a given horizontal angle.

To facilitate calculation of such a beam pattern, the Figure 8-2 data were smoothed somewhat using linear segments. The modified figure of merit function is shown in Figure 8-3 by unfilled data points. The solid data points show the Figure 8-2 data for reference purposes. Based on the vehicle detection data and on the Kirkpatrick et. al. (1984) figure of merit, it is suggested that a DRL lamp have a maximum intensity of 2000 cd. at -10 degrees and intensities at other angles which are the products of 2000 cd. and the figure of merit from Figure 8-3. This horizontal pattern would be provided in the horizontal plane ahead of the DRL lamp.

The intensity pattern above the horizontal should probably be limited based on the rearview mirror glare data. The vertical viewing angle from a DRL lamp to the rearview mirror of a lead vehicle depends on the heights of the lamp and mirror and on the lead distance. The mirror and lamp height dimensions will obviously vary between vehicles. Relevant dimensions of the test vehicle used in the current experiments (a Ford Escort) were taken as representative. For this vehicle, the turn signals are centered about 25 inches above the ground and the rearview mirror is centered about 48 inches above the ground. The distance from the rearview mirror to the rear of the vehicle is 8 feet. It is assumed that DRL lamps would be located at about the same height as the turn signals. In the rearview mirror glare experiment, the lamps were located 20 feet behind the rear of the car. If DRL lamps were mounted at the assumed height of 25 inches and located 28 feet behind the mirror, then the vertical angle from the center of the DRL lamp to the mirror would be approximately 3.9 degrees. At this vertical angle, the DRL intensity should be limited by the rearview mirror glare experiment data. In terms of rating of discomfort glare shown in Figure 7-1,

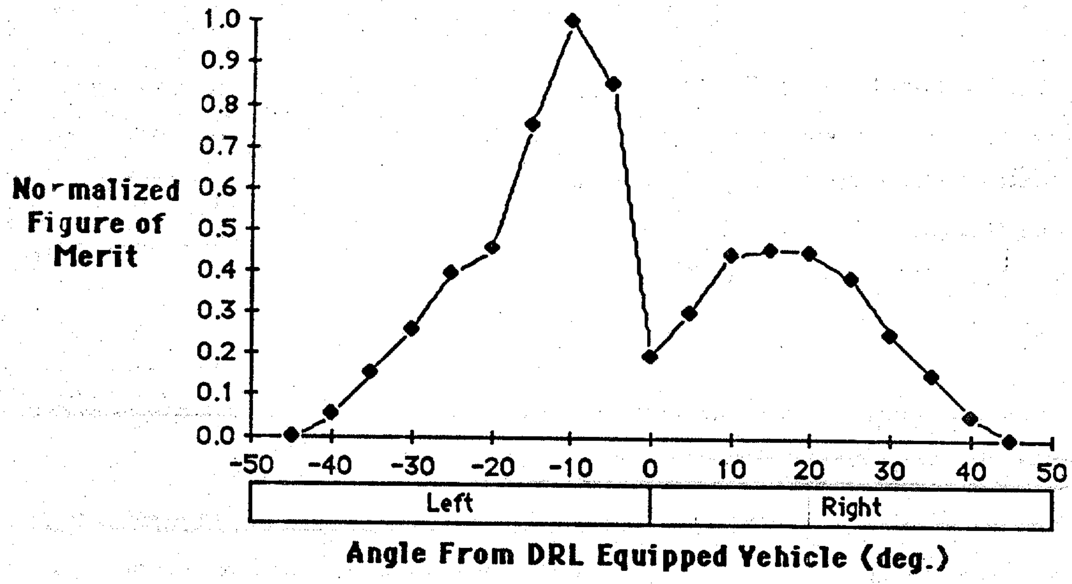

Figure 8-2. Normalized Figure of Merit for DRL Light Emission as a Function of Viewing Angle From Equipped Vehicle (From Kirkpatrick et. al. 1984)

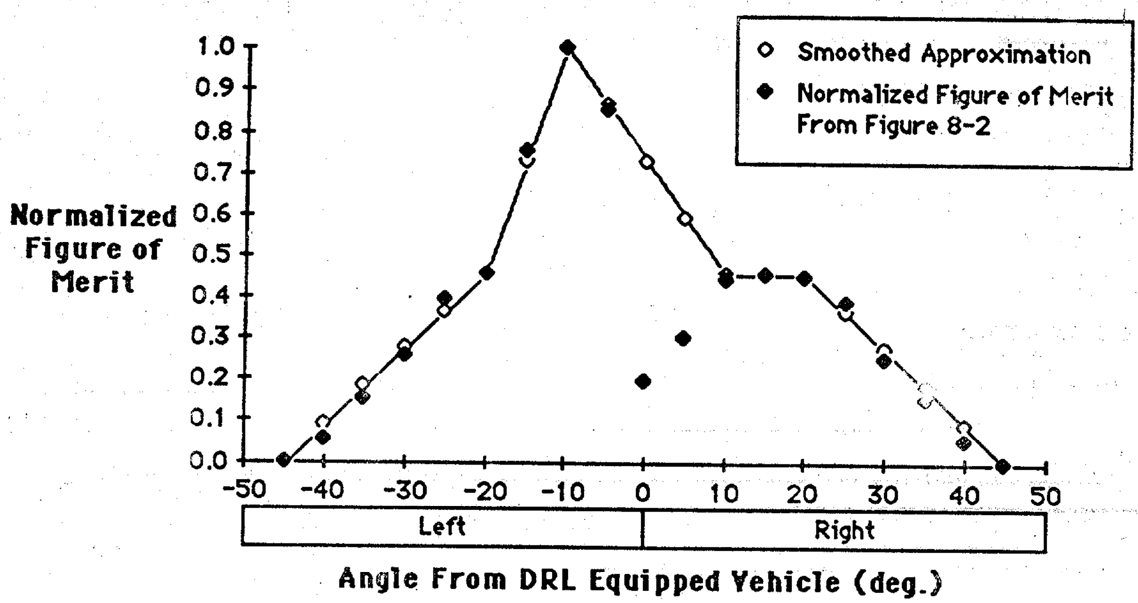

Figure 8-3. Smoothed Approximation to Normalized Figure of Merit

the 500 cd. intensity condition produced a mean value in the satisfactory range while the 1000 cd. and 2000 cd. produced mean values corresponding to just admissible and disturbing respectively. The effect of DRL intensity on the probability of mirror dimming is shown in Figure 7-3. This was found to increase from .13 at 500 cd. to about .78 at 2000 cd. Thus, both measures provide evidence of increasing discomfort glare above 500 cd.

The rearview mirror results only apply to the viewing distance used in the experiment. This was selected to approximate a worst case following distance. Clearly, for greater following distances glare will diminish rapidly because of the inverse square law. Assuming the rearview mirror experiment to represent a minimum following distance, it would appear desirable to limit DRL intensity at 3.9 degrees above horizontal to 500 cd. to minimize discomfort glare and the need for mirror dimming. The practice of specifying beam patterns in 5 degree increments, however, will be accepted here and it is proposed that the maximum DRL intensity at 5 degrees up be 500 cd. The same limit was taken as acceptable at 5 degrees down although this parameter is really not impacted by the study findings.

A recommended beam pattern based on the above considerations is shown in Table 8-1. In Table 8-1 the maximum intensities are located at 10 degrees left. These values are 2000 cd. at the horizontal (H) position and 500 cd. at 5 degrees above and below. Intensities at horizontal angles are products of the maximum for the row at 10 degrees left and the smoothed figure of merit from Figure 8-3. It would be desirable to have the intensity be uniform across horizontal angles at which the figure of merit is not zero (40 degrees left to 40 degrees right). Since this is impractical, however, the figure of merit approach has been suggested as a means of deriving design target intensity values. The beam suggested in Table 8-3 is certainly a "wide" one. It should not, however, represent an engineering impossibility. Measured intensities on the order of 50 percent of maximum at 20 to 30 degrees off center and on the order of 10 percent of maximum at 40 to 45 degrees off center were reported for selected vehicle turn signal/parking lamp units by Kirkpatrick et. al. (1984). Application of the figure of merit approach yields intensities less than 500 cd. at horizontal angles beyond 35 degrees left and right in the horizontal plane. This may not be of much practical benefit because the vehicle detection results did not show much improvement below 500 cd. It may be preferable to provide 500 cd. out to about 35 degrees left and right rather than spread the beam in the periphery as is suggested in Table 8-1.

The beam suggested in Table 8-1, although "wide", is not very "tall". The Swedish DRL standard shown in Figure 3-1 specifies minimums at 10 degrees above and below horizontal. While some beam "height" is certainly required to allow for aiming errors and hills, it is believed that a beam which is not much more than 10 degrees "tall" can probably accommodate these considerations. The vertical dimension subtended by a 10 degree beam at a characteristic detection

Table 8-1. Recommended DRL Intensity and Beam Pattern

		Left									Right							
Horizontal Angle From DRL Equipped Vehicle (deg.)		40	35	30	25	20	15	10	5	V	5	10	15	20	25	30	35	40
Smoothed Figure of Merit		.091	.182	.273	.365	.456	.728	1.000	.864	.728	.592	.456	.456	.456	.365	.273	.182	.091
DRL Intensity (cd.) as a Function of Horizontal and Vertical Angle	5 deg. Up	46	91	137	183	228	364	500	432	364	296	228	228	228	183	137	91	46
	H	182	364	546	730	912	1456	2000	1728	1456	1184	912	912	912	730	546	364	182
	5 deg. Down	[illegible]	91	137	183	228	364	500	432	364	296	228	228	228	183	137	91	46

distance such as 600 feet is on the on the order of 100 feet. It would seem that light energy emitted at larger vertical angles than this would be better applied if it were concentrated at the smaller vertical angles.

It is suggested that the intensities given for the 5 degree up vertical angle be taken as minimums with the exception of the peak at 10 degrees left. 500 cd. is considered to be a limit at any horizontal angle in the 5 degree up row. The intensities at the horizontal position should be considered minimums. If greater intensity can be maintained in the periphery, this is probably desirable. If intensities in the 5 degree down row can be increased above those shown without loss in the horizontal plane, this is also desirable. The 5 degree down values in Table 8-1 are not constrained by the current study. These were chosen largely on the assumption that loss of intensity in the vertical direction will probably be necessary to maintain the "wide" beam suggested here.

8.2 Lamp Separation

Effects of a single center mounted lamp versus dual separated lamps were evaluated in the vehicle detection and rearview mirror glare experiments. In terms of vehicle detection distance, the mean for the single lamp condition was found to be 647 feet while that for dual lamps was 674 feet. This difference was found to be significant at the .001 level in the analysis of covariance shown in Table 5-5. The separation effect was not found to be significant in the detection distance regression analysis shown in Table 5-2. This difference is probably due to the greater power of the analysis of covariance relative to the regression analysis. In the former, the main effect of subjects and the two-way interactions of independent variables were removed from the error term while, in the latter these sources were included in the error term.

This finding would appear to argue for dual rather than single DRL lamps. It should be noted, however, that comparison of the dual and single lamp conditions also involved differences in intensity. As discussed in Section 5.2, the DRL intensity variable was implemented on a per lamp basis. For a given intensity level, such as 1000 cd., the single center-mounted condition involved one such lamp while the dual condition involved two. If DRL intensity were taken as the total luminous intensity emitted from the front of the vehicle, then the levels would be doubled for the dual condition relative to the single center-mounted one. Adjusted detection distance data were plotted in this fashion in Figure 8-4 where the intensity levels for the single lamp condition are the nominal ones (250, 500, 1000 and 2000 cd.). The corresponding levels for the dual condition are 500, 1000, 2000 and 4000 cd. The slopes of the functions representing the two separation conditions appear to be quite similar and this suggests that a single lamp implementation would probably be about as effective as a dual one if total intensity were equated. Nevertheless, there may be other factors which support the dual DRL approach. For one thing, two separated lamps define a dimension to the observer. The rate of change of visual angle subtended by an approaching object depends, among other things, on the size of the object and is a perceptual cue to the speed of approach. The DRL separation dimension could therefore serve as a cue to the speed of an approaching vehicle. This dimension would not be available if a single centered DRL were used.

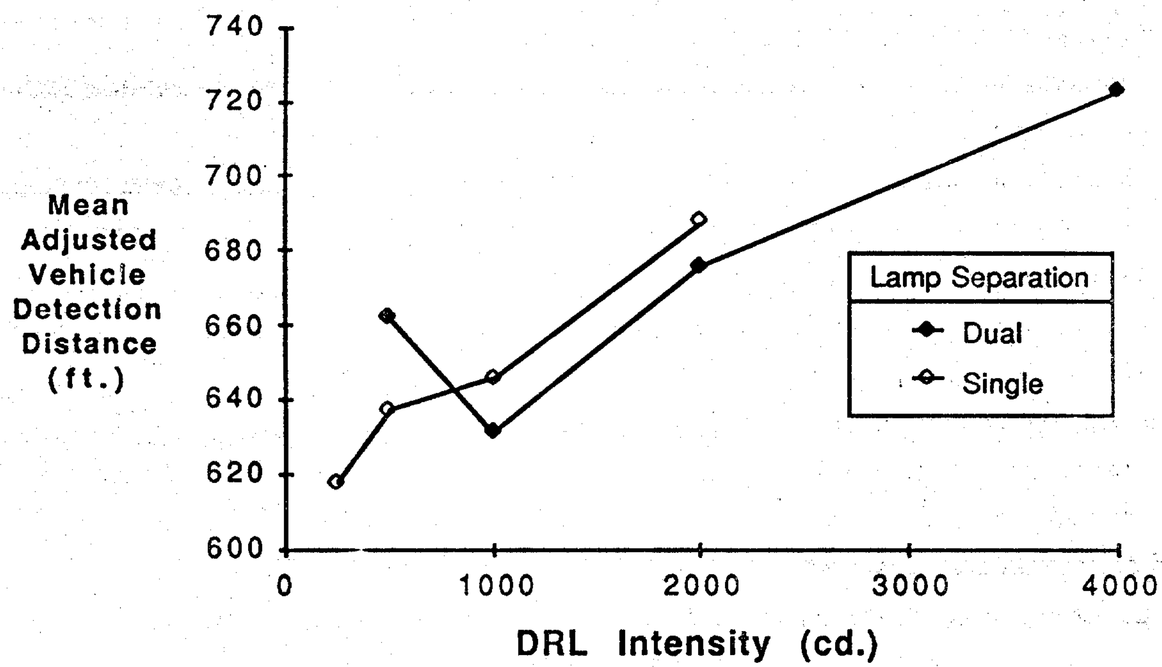

Figure 8-4. **Mean Adjusted Vehicle Detection Distance as a Function of DRL Intensity and Lamp Separation - Analysis of Covariance Data From Non-Zero Intensity Treatments and Subject Groups 1-4**

Dual DRL lamps were found to produce a slightly worse discomfort glare rating than did a single lamp ($P<.05$). It should be kept in mind that this effect resulted from the analysis of variance data in which intensity was treated on a per lamp basis. No significant effect of separation on probability of rearview mirror dimming was detected. As shown in Figure 7-1, the impact of separation on mean discomfort glare rating is much smaller than is that of DRL intensity. It is suggested that limitation of DRL intensity at 5 degrees up as discussed in Section 8.2 will effectively minimize discomfort glare due to dual DRL lamps.

8.3 DRL Lamp Area and Color

Effects of amber and clear lamps with area in the range from 50 to 200 sq. cm. were studied in all the experiments conducted here. The significant effects identified were mainly interactions between lamp area and color so these are discussed together.

Lamp area was not found to exert a significant main effect on mean vehicle detection distance but did interact with lamp color. The Figure 5-11 data for subject groups 2-4 show that for DRL lamp areas in the 50 to 100 sq. cm. range, the amber lamp condition produced greater average detection distances than did the clear condition. This difference in mean detection difference for amber versus clear lamps having areas of 50 to 100 sq. cm. was found to be significant at the .01 level using a Scheffe test. Thus, an amber color would be recommended over clear for DRL lamps in this size range which encompasses typical parking, turn signal and fog lamps. The interaction of area and color was due largely to the contrast between the 50 to 100 sq. cm. conditions and the 200 sq. cm. condition. The latter is a characteristic area for a single headlamp. The Figure 5-11 data strongly favor a clear lamp at this size level. In any event, it is not obvious how the amber 200 sq. cm. case could be implemented short of producing an amber headlamp.

Lamp area produced several complex effects on the degree of turn signal masking resulting from an adjacent DRL as measured by the probability of correct turn signal detection. The main effect of lamp area as shown in Figure 6-1 was significant at the .001 level and consisted of a regular decrease in probability of correct turn signal detection as area increased from 50 to 200 sq. cm. This effect was also found to depend on viewing distance and lamp color and to interact with DRL intensity. The interaction effects as shown in Figures 6-3 to 6-5 involved a fairly regular decrease in probability of correct detection with increasing lamp area and increasing DRL intensity. For the amber lamp condition, the interaction effects were somewhat more complicated. Amber lamps having areas greater than 50 sq. cm. produced decrements in probability of correct detection and the magnitudes of these depended on intensity and viewing distance. The ratings of turn signal difficulty were in agreement with the detection probability data as regards the effect of lamp area. The mean difficulty rating showed a regular and statistically significant increase with increasing lamp area.

The minimal turn signal intensity and separation from the DRL used here were intended to represent a worst case. Under these conditions, an argument could be made that if amber DRL lenses are used (based on the conspicuity results), then the area should be limited to 50 sq. cm. to avoid turn signal masking. A more practical approach, however, would seem to involve increasing the DRL to turn signal separation and/or increasing turn signal intensity. An implementation using the turn signals as DRL when they are not activated as turn signals would solve the problem as would turning off the DRL when the turn signal is activated.

In general, the greatest degrees of turn signal masking were associated with 200 sq. cm lamps having an intensity of 2000 cd. This may argue against the use of headlamps as DRL although, the negative consequences of larger DRL area reported here can probably be avoided simply by increasing the separation between the DRL lamp and the turn signal.

The main effect of lamp area on mean discomfort glare rating in the rearview mirror glare experiment was found to be significant at the 0.05 level. As shown in Figure 7-1, this effect was due to the 200 sq. cm. area condition which produced a less favorable mean rating in comparison with the smaller areas which were judged to be equal. The lamp area effect on perceived glare was not supported by the probability of mirror dimming data and no significant effect of lamp color was identified in the rear mirror glare experiment.

8.4 DRL Background Contrast

The main effect of background color on vehicle detection distance was not found to reach statistical significance. Background color did, however, interact significantly with lamp color and separation. The background by lamp color interaction shown in Figure 5-12 for subject groups 2-4 was due to the fact that a black background produced greater detection distances than did a white one but only for amber lamps. If amber lamps are selected, provision for a darker background would appear to be worthwhile. If clear DRL lamps are used, the data suggest that the background will make little difference.

The data generally supported the notion that lamp intensity rather than luminance is the factor which drives conspicuity. Lamp luminance as defined for purposes of the current study is the ratio of total intensity to area (i.e. cd. per sq. cm.). If this were the effective stimulus property in determining conspicuity, then area and intensity should have shown strong interactions. In fact, however, the area x intensity interaction was not found to reach statistical significance in any of the experiments.

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